

**UNDERSTANDING TECHNOLOGY DIFFUSION AND MARKET ADOPTION  
THROUGH MODELING: IMPLICATIONS ON STRATEGY FOR DEMAND-SIDE  
ENERGY FIRMS**

By

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B.E. Electronics and Communication  
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Submitted to the System Design and Management Program  
in Partial Fulfillment of the Requirements for the Degree of

**Master of Science in Engineering And Management**

At the

**Massachusetts Institute of Technology**

June 2012

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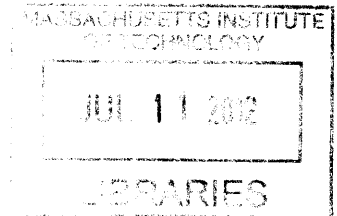
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By

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Submitted to the System Design and Management Program in Partial Fulfillment of the Requirements for the Degree of Master of Science in Engineering And Management at the Massachusetts Institute of Technology

## **Abstract**

Deregulation shaping the Electricity industry across the world is a systems challenge cutting across interdisciplinary fields of technology, economics, public policy, environment and sociology. Decision makers that shape tomorrow's policy and investors that invest in financial and technological developments in this industry need to rely on multiple decision models to make informed decisions. This thesis serves to provide one such decision model among many that could be used to understand the key dynamics shaping a highly complex industry.

We employ "top-down" and "bottom-up" approaches to build system dynamics model in an attempt to distinguish between adoption and diffusion phenomenon, as a result benefiting from hybrid modeling techniques that combine structures from both models. The models are evaluated with wide range of scenarios to arrive at policy guidance and business model recommendations.

The dynamic hypothesis arising from our system dynamics model points to declining marginal profits in a saturating market coupled with proliferation of competitors, over-estimation of demand and diminishing margins for Curtailment Service Providers (CSPs) in the long run. We propose recommendations to surmount these challenges. To tap the smaller commercial and residential markets, CSPs must extend its reach by partnering with composite channel partners, who in the long run could also play a vital role in demand generation. In the face of commoditization and disruptive innovations, CSPs would not be able to sustain their margins just by aggregating demand response (DR) capacity; they would need to reinvent themselves to become energy management firms providing integrated, automated turnkey energy services including energy efficiency services, risk management, planning, sourcing along with providing DR services.

Taking a systems approach in evaluating demand-side technology, we further investigate environmental implications of DR by characterizing the carbon savings from DR. Our analyses revealed that the carbon savings from DR triggered load curtailment when calculated using system wide carbon intensities differ substantially from those calculated with locational carbon intensities. Locational carbon intensity captures the location and time-specific dynamics of electricity demand. We, therefore, recommend it is a better metric for evaluating total carbon savings from load curtailment, which could be used to devise carbon abatement policies and structure the electricity market design rules. Furthermore, adding a carbon price to the marginal cost equation could change the dispatch order of plants and thus align carbon abatement policies with load reduction schemes.

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## Acknowledgments

I would like to express my most sincere gratitude to Professor Henry Birdseye Weil for his guidance, support, and encouragement throughout the development of this thesis. I am indebted to you for focusing the topic, for our numerous discussions and reviews, and insights that I learned from you. Association with you has truly influenced my thinking and I remain grateful forever.

My gratitude goes out to my numerous friends at MIT and Sloan who have contributed to this thesis in some way or other. This thesis is largely possible because of the teamwork that we did, ideas that you shared, the questions you asked, and the answers you gave. You are among the best and brightest.

Numerous courses that I took during my time at MIT has influenced this thesis in some way, chief among them are - Competitive Dynamics and Strategy taught at MIT Sloan by Prof. Weil, Mapping and Evaluating New Energy Technologies taught at MIT by Prof. Jessika Trancik, Business Marketing and Sales taught at Harvard Business School by Prof. Thomas Steenburgh, and Technology Strategy taught at MIT Sloan by Prof. James Utterback. In addition to these, I'm deeply indebted to two works of excellence - "Business Dynamics" by Prof. Sterman and "Clockspeed" by Prof. Charles Fine. These works magnified my understanding of the subject by leaps and bounds.

I would like to thank Prof. Trancik for her constant encouragement and probing questions that led me to focus on the environment implications of demand-side technologies along with Jake Whitcomb. Jake, your collaboration was very valuable and I hope we carry this partnership forward.

I take this opportunity to thank the SDM cohorts, the energy conference team, and Prof. Harvey Michaels, who all contributed to my learning experience. I would also like to thank Pat Hale for giving me the opportunity to be part of one of the finest programs at MIT and Sloan.

A special thanks goes out to all those who worked with me during my stay at MIT. It was a pleasure working with you all; hope we collaborate again.

Most Importantly, I owe this work to my loving parents, dearest sister Misha, and my lovely little nephew for all you have been to me. In spite of the physical distance, you were all with me every moment as I lived this dream. This work is dedicated to you!



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## Chapter 1 – Introduction

Growing up in an energy poor nation has exposed me to grim realities of energy shortage. It was hard coming to terms with frequent and incessant power cuts; and one should never, especially so in 21<sup>st</sup> century. Access to electricity remains a dream for billions of people worldwide. The topic of energy-poverty-climate nexus is a well-examined one, and without providing electricity to all the masses, eradicating poverty will never become a reality.

Energy issues have been contentious topic among countries for many decades and are becoming increasingly so. The three main energy problems facing the globe are often broadly classified as concerning- energy access, climate change, and energy security. Policy makers are faced with the challenge of addressing these issues at the same time. Through this thesis, I wish to explore the role of demand side energy technologies in alleviating the world's energy needs. Although demand side technologies such as energy conservation and energy efficiency can do little to solve the energy access problems facing the less developed world, it is a step in the right direction by enabling the developed world to reduce its reliance on more energy resources while also reducing the impact on climate from Green House Gas emissions at the same time.

Technology and Market-led programs alone cannot address the energy problems facing the developing world today. They should be fostered with concerted policy, environmental, sociological and economic instruments to improve energy access, mitigate adverse climate effects, and alleviate poverty. In this thesis, we would explore the demand side energy technologies from multiple lenses, as energy problem is not a one-dimensional issue but a systems challenge.

Our objective is to capture and analyze the fundamental dynamics in energy demand side sector with a system dynamics model. Some of the key questions that this thesis will help address are:

- Who is the primary beneficiary of demand response technology and what are their needs?
- Who are the secondary beneficiaries of the demand response technology?

- What factors are most important to the stakeholders in embracing demand response technology?
- How do these factors differ across different stakeholders?
- What are the current dynamics and how will they evolve in future?
- How will these dynamics shape the technology diffusion of Demand Response?
- What are some of the strategy and policy implications that emerge out of the key dynamics?
- Are there any environmental benefits or impact of Demand Response?
- Can the environmental benefits or impact be quantified? If so, are they different across regions?

By answering these questions, we also hope to increase the understanding of decision makers (energy planners, investors, policy makers and regulators) using this model. We also hope that this thesis assists the decision makers in making more informed decisions and enables businesses in scenario planning and strategic analysis.

## **Thesis Structure**

The Chapter 1 in this thesis outlines the motivations and research questions that it addresses. Chapter 2 provides a brief introduction to deregulated electricity market and Demand Response sector and its value chain elements. It also details the different program types of demand response. Chapter 3 starts with a brief description of technology diffusion and different models of diffusion. It then explains the choice of System Dynamics as a methodology of this thesis. It goes on to introduce the taxonomy of technology diffusion and technology adoption before discussing the top-down and bottom-up approaches.

Chapter 4 describes the technology adoption model and lists the market dynamics that emerged after thorough literature review and analysis of pilot programs. Then, we build bottom-up models for technology adoption from individual stakeholder's perspective.

Chapter 5 builds the technology diffusion system dynamics model using the top-down approach and explains the key structures in detail.

Chapter 6 provides the model results, performs sensitivity analyses, and builds and tests various scenarios.



Chapter 7 describes the implications that arise from the model results on strategy framing for CSPs.

Chapter 8 discusses the environmental impact and benefits of demand response and arrives at a formulation for locational carbon savings from demand response led load curtailment.

Chapter 9 concludes with policy and strategic recommendations and further explorations based on this thesis.

Appendix lists the formulation of the System Dynamics Model.

## Chapter 2 – Deregulated Electricity Market Structure and Demand Response

FERC defines Demand Response (DR) as the “Changes in electric usage by end-use customers from their normal consumption patterns in response to changes in the price of electricity over time, or to incentive payments designed to induce lower electricity use at times of high wholesale market prices or when system reliability is jeopardized”. Before building the model of the demand-side innovations in energy system, it is important to understand the ecosystem and value chain each innovation is operating in. The following illustration captures the different value system players and their operational, financial and regulatory bindings in the demand response sector.

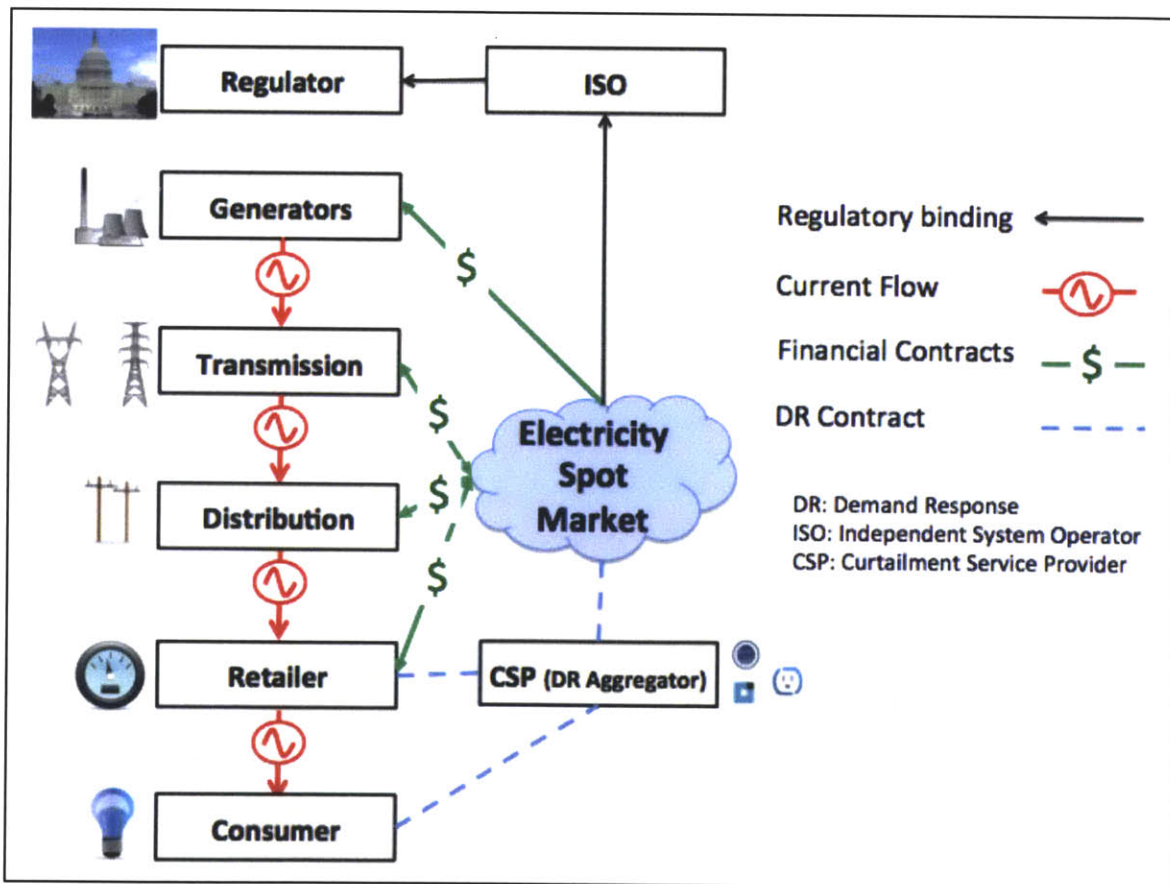


Figure 1 Value Chain of Demand Response Market

The key players who make up the value chain in the demand response industry sector operating in a restructured market are the Generators, Transmission line operators, Distribution system operators, the retailer (utility), the Consumer, and the Curtailment Service Provider (also called Demand Response aggregators). Apart from these players, there is also the Independent System Operator (ISO) and the regulatory body.

In a restructured or deregulated electricity market, the traditional utility performs the role of transmission and distribution (sometimes only the latter) and owns and maintains its infrastructure. The generation and retail ends of the business are divested and are open to competition. In the following paragraphs, we provide a brief overview of the different roles these players deliver in the value chain.

**Electricity Consumer:**

The consumers constitute all the end-customers that consume electricity. Broadly, they are classified as residential, commercial and industrial customers.

**Regulator:**

Federal Energy Regulatory Commission (FERC) is the Federal regulatory body with jurisdiction over interstate electricity sales, wholesale electric rates, hydroelectric licensing, natural gas pricing, oil pipeline rates, and gas pipeline certification in the USA.

**Generators:**

Generators generate electricity and deliver power for transmission and distribution to the utility. They operate as independently owned and provide energy, capacity and ancillary services to the utility or sometimes to industrial customers. They sell directly to the market participants in the electricity market.

**Independent System Operator (ISO):**

An independent, federally regulated entity established to coordinate regional transmission in a non-discriminatory manner and ensure the safety and reliability of the electric system (FERC). They are also referred to as Regional Transmission Organization (RTO) in some markets.

**Transmission Owners:**

Transmission owners are independent owners of the transmission infrastructure and transmission rights. Most often they are the remnants of the utilities and operate the transmission facilities under the bindings of the ISO.

**Utility Distribution Companies:**

The utility distribution company performs the role of providing electricity service to customers.

**Curtailement Service Provider:**

Curtailement Service Provider or the demand aggregators hereon referred to, as CSP are the companies that aggregate capacity from end consumers to provide load curtailement services to the ISO and utilities at times of peak load in exchange for capacity or energy payments.

In addition to these major roles, there are other entities, which perform overlapping role such as a load serving entity, which is used to refer to a market participant that provides supply to end customers. They are sometimes called **retailers** and often are the distribution companies themselves.

**Electricity Markets**

The world over the last two decades has seen a steady progress in liberalization of the electric energy industry. The electricity industry is unique in many different ways that makes the operation of electricity market an extremely complex systems challenge.

Electricity has some physical properties that set it apart from other commodities and makes it inherently complex to trade on the market. First, electricity cannot be stored. There is no such thing as inventory for electricity. This implies that supply and demand should be matched in real time. Failure to do so could lead to blackouts. Second, electricity follows the path of least resistance. This means that the grid consisting of generating plants, transmission lines and the consumer loads should be balanced in real time to prevent overloading or under-powering the equipment. Third, physically the grid is comprised of highly complex and interdependent network of generators, transmission, and distribution systems. There is little scope for error in balancing and meeting the

needs, lest there could be outages at the regional or national scale. Finally, the frequency of electric signal has to be maintained within a narrow band. Any deviation beyond the margin could lead to destruction or malfunction of consumer's loads.

While the abovementioned complexities arise out of physical properties of electricity, there are other structural complexities in the market that complicate the markets further due to the shared regulatory jurisdiction between federal and state regulators in the USA. The FERC regulates the wholesale trading, transmission, system operation, and markets whereas the states are in charge of breaking up the vertical utilities and enabling retail competition. The rollout of retail competition at the state level is fragmented. Some states have taken the lead and deregulated whereas some others have chosen to stay put with the traditional vertically integrated utility structure. Even when the states have restructured their utilities, no two regions have done it exactly alike(Shively & Ferrare, 2010). Some have transitioned their existing power pools while some others have created new regional system operators(Shively & Ferrare, 2010).

Many of the players described earlier in the value chain operate in the wholesale market place to trade different electricity services. The below figure from (Shively & Ferrare, 2010) illustrates in a succinct manner the diverse set of stakeholders and the services traded in the wholesale marketplace.

<b>WHOLESALE SERVICES</b>		
<b>Service Provided</b>	<b>Service Provider</b>	<b>Service Consumer</b>
<b>Energy (MWh)</b>	Merchant generators Utilities Federal power agencies ISOs Wholesale marketers	Utilities ISOs Wholesale marketers Retail marketers Large end users
<b>Capacity (MW)</b>	Merchant generators Utilities Federal power agencies ISOs Wholesale marketers	Utilities ISOs Wholesale marketers Retail marketers
<b>Transmission Rights</b>	Utilities Transmission companies ISOs	Merchant generators Utilities Wholesale marketers Retail marketers
<b>Financial Risk Management</b>	Financial companies ISOs Wholesale marketers	Merchant generators Utilities Wholesale marketers Retail marketers Large end users

Figure 2 Wholesale Market Services<sup>1</sup>

In addition to the above listed existing wholesale services, a novel type of load reduction service referred to as Demand Response is actively traded in the wholesale capacity markets. We will discuss it in detail in the following section.

### **Demand Response**

Demand Response forms a part of the load management programs in the broader Demand Side Management (DSM) portfolio. Energy efficiency and Energy conservation programs constitute the remaining programs in the DSM portfolio.

---

<sup>1</sup> Source: (Shively & Ferrare, 2010)

Demand Response not only averts blackouts, but also reduced energy prices in the spot market during times of peak demand. We illustrate this with the help of the conceptual figure below from the Brattle group report. In most electricity markets, the retail consumers pay a fixed price to the utility for their electricity consumption. However, the utilities have to compensate the generators at the market-clearing price, which is determined by a combination of the capacity and energy price from the wholesale, and spot markets. Consequently, even when the energy prices spike at times of congestion or peak demand, the end consumers do not reduce their consumption in reaction to the increased prices in the spot market. This means the price elasticity of electricity demand approaches zero, which is unreal practically. In reality, the utilities will have to pay the market-clearing price represented by the intersection of the supply and demand curves in the figure below. Now, if the demand is curtailed when the prices are increasing, then the demand curve shifts from point Q1 to Q2. This causes the price to decrease from point P1 to P2 resulting in a net benefit, which can be quantified by the area bounded by the curve 'aefg'. The Brattle group report on quantifying demand response benefits in PJM further highlights the area abgf as the efficiency gain from not using expensive resources (Felder & Newell, 2007).

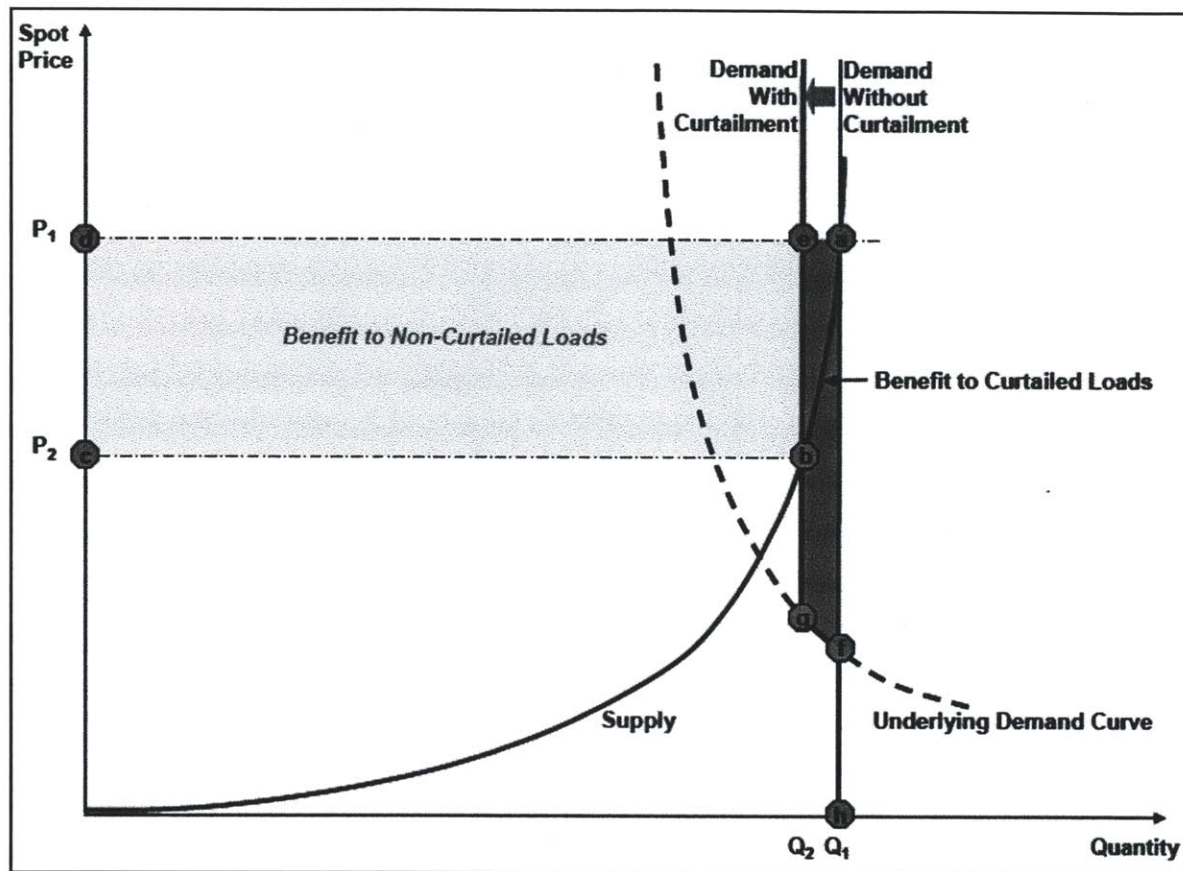


Figure 3 conceptual plot of energy benefits to curtailed load<sup>2</sup>

Demand Response programs have existed for decades, albeit in different forms. Traditional utilities have historically offered large industrial customers lower tariffs than the market price in exchange for an agreement to curtail their loads during system contingencies. Such programs were called interruptible load programs. Similarly, there existed “Direct Load Control” programs that controlled customer loads such as HVACs, in return for lower rates.

In the last few years, the Demand Response programs have matured and become more sophisticated with increased penetration of advanced metering infrastructure (AMI), energy efficiency solutions and curtail-able loads that can be remotely controlled. This has allowed the demand response

<sup>2</sup> (Felder & Newell, 2007)



programs to be offered to smaller industrial and commercial customers too. In a few cases, they have also been piloted for residential customers.

The Demand Response programs can be broadly classified as “Dispatchable” and “Non-dispatchable”. “Dispatchable” demand response refers to planned changes in consumption that the customer agrees to make in response to direction from the curtailment service provider or the utility or ISO. On the other side of the spectrum are “Non-dispatchable” demand response programs that refer to programs in which the customer decides whether and when to reduce consumption based on a retail rate design that changes over time(Federal Energy Regulatory Commission, 2010).

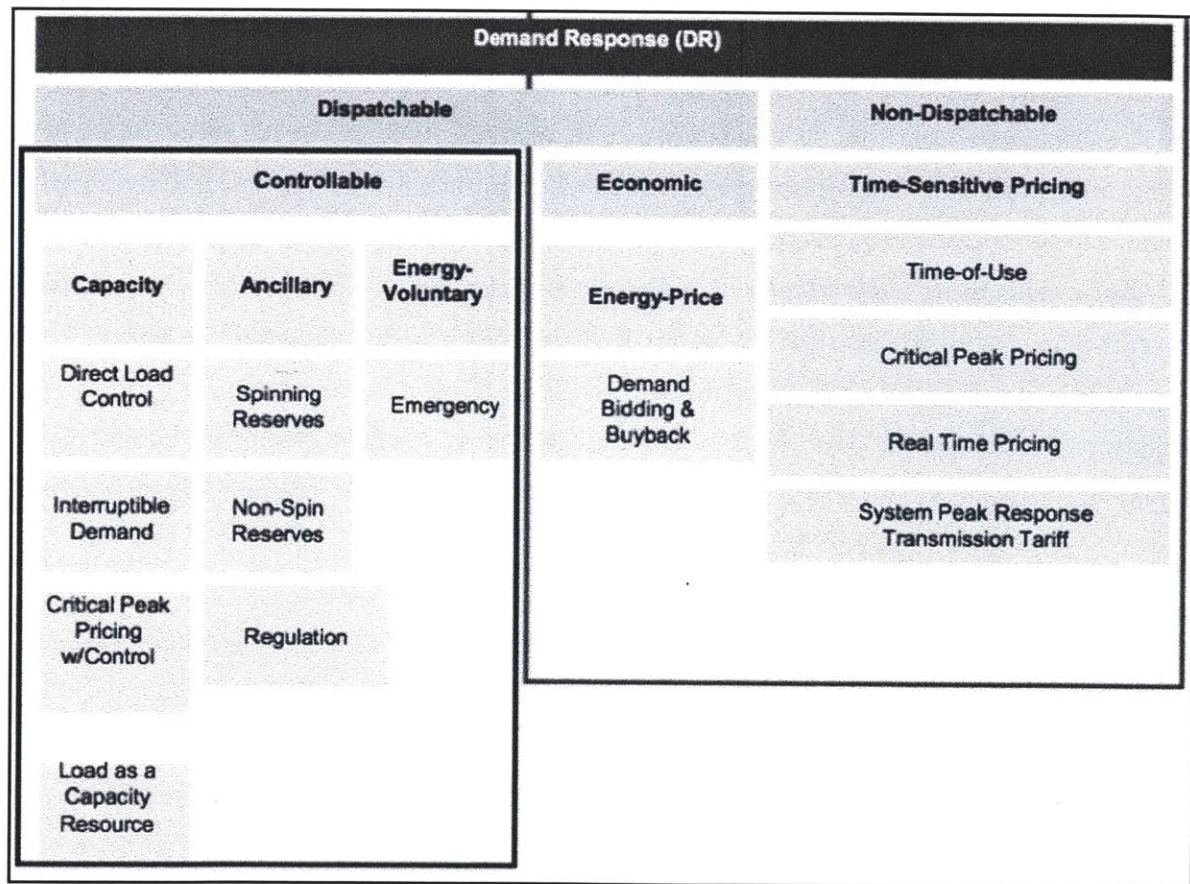


Figure 4 DR Program Type Classifications<sup>3</sup>

<sup>3</sup> Source: (North American Electric Reliability Corporation, 2007)

The “Dispatchable” demand response programs can be categorized as Controllable and Economic as depicted in the figure above. The Controllable DR programs can further classified based on their purpose as Capacity type, Ancillary services, and Emergency programs.

The Capacity programs includes “Direct Load Control” and “Interruptible Load” discussed earlier and “Critical Peak Pricing with direct load control” (CPP w/ Control), and “Load as Capacity Resource”. The CPP w/ Control combines direct load control with a pre-specified high price for use during designated critical peak periods, triggered by system contingencies or high wholesale market prices, whereas under the Load as Capacity Resource, customers make an agreed load reduction when system contingencies arise(Federal Energy Regulatory Commission, 2012).

Ancillary services require more stringent requirement from the enrolled customers in the sense that the dispatch requirement from the load is almost instantaneous. Ancillary services are of three types – “Spinning Reserves”, “Non-Spinning reserves”, and “Regulation Service”. Spinning Reserves are required to be synchronized and capable of providing solutions for energy supply and demand imbalance within the first few minutes of an Emergency Event. Non-Spinning reserves have slightly lower requirement in the sense that it need not be immediately available, but it must be able to provide solutions for energy supply and demand imbalance after a delay of ten minutes or so. Regulation Services are subject to dispatch continuously during a commitment period. In this type of service, the Demand Resource increases and decreases load in response to real-time signals from the system operator(Federal Energy Regulatory Commission, 2012).

Emergency programs provide incentive payments to customers for load reductions achieved during an Emergency Demand Response Event(Federal Energy Regulatory Commission, 2012).

The “Non-dispatchable” DR programs are sometimes also called retail price-responsive DR. It includes dynamic pricing programs that levy higher prices during peak hours and lower prices at off-peak hours. Usually, the rate structure is so designed so as to encourage reduced consumption during periods of high wholesale market prices or system contingencies(Federal Energy Regulatory Commission, 2012). In this thesis, our focus would be on the technology diffusion of Dispatchable

demand response programs, as “Non-dispatchable” are largely dependent on price elasticity of demand and constitute a smaller fraction of overall DR enrollment. “Non-dispatchable” programs are described in further detail in FERC-731 Demand Response/Time-Based Rate Programs and Advanced Metering.

Demand Response is increasingly accepted, as a reliable and cost-effective way to meet system resource needs. As discussed in preceding paragraphs, each of the different demand resource types offers unique value to utilities and consumers. The following figure illustrates different types of demand response types on offer from CSPs.

	Economic	Emergency	Ancillary Services	Peaking Alternative
<b>Program Compensation</b>	Energy payments (\$/kWh)	Capacity & energy payments (\$/kW-month and \$/kWh)	Availability & energy payments (\$/kW-hour and \$/kWh)	Capacity & energy payments (\$/kW-month and \$/kWh)
<b>Performance Measurement</b>	Difference between load-adjusted customer baseline and actual load	Difference between load-adjusted customer baseline and actual load	Difference between pre/post-event and event load	Difference between load-adjusted customer baseline and actual load
<b>Response Time</b>	Day-ahead or day-of	30 minutes to day-ahead	Less than or equal to 10 minutes	10 - 60 minutes
<b>Program Availability: Days</b>	Markets are 24/7/365; resources can bid in reductions	Typically business hours, working days; also 24/7 programs.	Markets are 24/7/365; resources bid in hours of availability	Typically business hours, working days; may also include weekends or 24/7 program hours
<b>Program Availability: Hours per Year</b>	Dependent on market bid	As defined by system conditions	Dependent on market bid	60 - 100 hours
<b>Program Availability: Duration</b>	1 - 4 hours	1 - 8 hours	10 - 60 minutes	1 - 8 hours
<b>Event Trigger[s]</b>	Economic dispatch	System conditions, such as actual or forecasted operating reserves shortage	System contingencies	At utility's discretion
<b>Program Penalties</b>	None; Loss of incentive payments	Loss of incentive payments and/or non-performance penalties below pre-determined threshold level	Loss of incentive payments and/or system tariff penalty payments	Loss of incentive payments and/or non-performance penalties below pre-determined threshold level
<b>Event Frequency</b>	At end-user's discretion	Low	At end-user's discretion / High	Medium-High
<b>Metering Requirements</b>	Preferably 5-minute interval data (15-minute or 1-hour data can suffice)	Preferably 5-minute interval data (15-minute or 1-hour data can suffice)	1- or 5-minute interval data	Preferably 5-minute interval data
<b>Communications Requirements</b>	Ability to receive day-ahead and real-time hourly energy prices	Ability to receive and confirm system operator requests, preferably with real-time performance transparency	Ability to receive and confirm system operator requests, preferably with real-time performance transparency	Ability to receive and confirm system operator requests, preferably with real-time performance transparency

Figure 5 Different Types of Demand Response<sup>4</sup>

<sup>4</sup> Source: (Enemoc, 2009)

## Chapter 3 – Technology Diffusion, Taxonomy and Methodology

### Technology Diffusion

The most essential part of innovation is its adoption by users, which at an aggregated level leads to diffusion of innovation to substitute an incumbent technology or create a discontinuity in the product or service space. Everett Rogers defines this diffusion of innovation as “The process by which an innovation is communicated through certain channel over time among the members of a social system” (Rogers, 2003). Rogers categorizes the various elements of diffusion of innovation into:

1. Innovation – an idea that is perceived as new by an individual or other until adoption.
2. Communication channels – the means by which messages get from one individual to another.
3. Time– Length of time required to pass through the innovation-decision process and the Rate of adoption.
4. Social system – a set of interrelated units that are engaged in joint problem solving to accomplish a common goal.

Broadly speaking, the purpose of diffusion models have been to facilitate theoretical explanation of the dynamics of the diffusion process and to predict or forecast the diffusion characteristics such as rate of diffusion, point of inflection, and the length of diffusion.

Geroski discusses in the paper “Models of Technology Diffusion”, two main diffusion models (epidemic and probit), and two alternate models that rely on density dependence and information cascades. Probit models base the process of diffusion through the lens of individual firms adoption decisions. Simplistically speaking, a firm bases its adoption decision based on the expected returns. The parameters defining the adoption decision are defined by various firm characteristics, size, suppliers the firm is working with, technological expectations, learning capabilities, switching and opportunity costs and others. Epidemic model is based on the assumption that what prevents a rapid diffusion of technology is the lack of information available about the new technology, how to

use it and what it does (Geroski, 2000). This model is dependent on two main factors - how many potential users of new technology there are and percentage of population that can be reached by the new technology at a given time. The source of the diffusion of technology is represented by current user base of the technology that grows over time. After the inflection point, the adoption rates slows down largely because it becomes harder to enroll non-users of the technology. Geroski lists other alternate models that explain the stylized S-curve such as the density dependent growth models that account for the systematic changes in net birth rates observed in natural settings. Lastly, Geroski discusses models that rely on information cascades in which the initial choice between different variants of the new technology affect the subsequent diffusion speed of the chosen technology (Geroski, 2000). These models account for herd-like adoption behavior as described by network and bandwagon effects.

Lyneis discusses in the “A Dynamic Model of Technology Diffusion” paper, the key concepts such as technological progress curves, cost-experience curves, price-performance curves, product lifecycle curves, substitution curves, and Fisher-Pry techniques used to understand the diffusion process. Although the paper highlights that these concepts provide support tools to forecast diffusion and shape strategy, Lyneis emphasizes that they are ineffective in developing a mental model in a decision maker’s mind (Lyneis, 1993). The paper demonstrates the use of system dynamics as applied to strategy to overcome the shortcomings of diffusion models and develop a deep understanding of the contextual dynamics of the system.

### **System Dynamics as a Methodology**

Many of the models discussed so far can fit data for a wide range of growth processes. Sterman explains that these models often work well at curve fitting as it “includes two feedback processes fundamental to every growth process - a positive loop that generates the initial period of accelerating growth and a negative feedback that causes the growth to slow as carrying capacity is approached” (Sterman, 2000). The essence of the models is not in forecasting but in understanding; Sterman illustrates three reasons that reinforce this statement. First, a single model can never fit all types of data equally well. Second, econometric techniques require long enough data for parametric estimation to fit a model. It takes a lot of time and effort for collecting data that by the time



sufficient data has been collected for reliable estimation, the product or innovation is so far advanced in the diffusion cycle that it renders the modeling redundant (Mahajan, Muller, & Bass, 1990). Third, growth models are static and if policies or other exogenous factors change, these growth models would need recalibration to fit the changed growth pattern arising from changed policies.

Sterman states “The utility of a model cannot be judged by historical fit alone”; instead the structure and decision rules of the model should demonstrate those of the real world with sufficient fidelity. To replicate such accuracy, models should incorporate the feedback structures endogenously. System Dynamics provides such a framework to build realistic models that provides insights into the dynamics of the system (Forrester, 1961). It evolved out of the seminal work of Forrester at MIT in the 1950s. System Dynamics framework provides rich and realistic feedback structures that model the important dynamics of the real world. It has been widely adopted for policy analysis to corporate strategy in wide range of industries such as aerospace, manufacturing, healthcare, energy and so on.

In this thesis, we will use system dynamics as our primary methodology to understand the dynamics shaping innovation and technology diffusion in energy demand side sector. In an attempt to capture the dynamics across the industry spectrum, our model would include all the models described in the review of works of Geroski. Although we will touch upon all aspects of the diffusion process, the primary focus of the thesis would be on the mature stages of a diffusion process when a few early adopters have already adopted the technology. Furthermore, we would be focusing on the industry level dynamics instead of organizational level decisions, although they would be accounted for in arriving at the dynamics.

The models that we build in this thesis will adopt a descriptive approach. The implications on strategy chapter would encompass recommendations that could help CSPs capture more value after understanding the industry dynamics.

### **Taxonomy of Technology Adoption and Technology Diffusion**

In this thesis, technology (or market) adoption refers to adoption or use of a technology from the participating stakeholder’s perspective. In the case of Demand Response technology, the

participating stakeholders are the Electricity consumers, the retailer (or utility), the independent system operator (ISO) and the DR aggregator (also called the Curtailment Service Provider). Accordingly, when we refer to market adoption it means the use of DR from the perspective of one of the above mentioned stakeholders.

Technology diffusion refers to the rate of growth of the technology, which can be measured through the market share penetration of the technology under discussion. The perspective view for technology diffusion is at a system level as opposed to the agent or actor level perspective when we refer to market adoption.

### **Discussion of Top-Down and Bottom-Up approaches**

Understanding the adoption and diffusion dynamics described above requires different approaches due to the different perspectives involved. Adoption is based on the decisions made at the entity or individual perspective level. Hence, understanding adoption dynamics needs a micro perspective dealing with the decision making from the actor's perspective. Thus, a bottom up approach will be followed to uncover the adoption dynamics for demand response. A bottom-up model evaluates the system based on technological breakthroughs and policy implications at a disaggregated level.

Technology diffusion, on the other hand, captures the view at a system level and not just from an actor's viewpoint. A macro level perspective is needed to capture the important behavior and decisions of multiple actors along with the interaction of competing and complementary technologies, influence of competition and learning curve effects. Thus, a top down approach is needed to gain a broader understanding into the diffusion process. Top-down models evaluate the system from aggregate macroeconomic variables.

IPCC summarizes the historic divide between "top-down" and "bottom-up" modeling approaches in its 1995 climate change report. The top down models began mainly as macroeconomic models that tried to capture the overall economic impact of a climate policy, which was usually in the form of a carbon tax or, more rarely, tradable permits. Bottom-up models, on the other hand, rely on the detailed analysis of technical potential, focusing on the integration of technology costs and

performance data(Bruce, Lee, & Haites, 1996). The IPCC report observes that the key differences between the two approaches are largely methodological such as how to describe the technology adoption process, the behavioral decision-making of economic agents, and the feedbacks between public policy measures.

In bottom-up approach, the adoption dynamics from individual actors are aggregated and incremental benefits and costs summed to arrive at the diffusion rate of the technology or innovation as a whole. This approach is centered on the premise that summation of individual decisions captures the dynamics of the system. Traditionally, such an approach did not account for externalities such as network and bandwagon effects and as a result yielded results different from those of a top-down approach. However, in our models we account for these externalities, but some externalities such as the effect of complementary and competing technologies and innovation is difficult to capture in an endogenous manner without detailing a bottom-up model for the externalities themselves. In contrast, the top-down approach, often do not capture the technological potential correctly.

Relying upon a single modeling technique or paradigm for decision making can be as deficient as relying upon point forecasts for predicting. Just as the National Hurricane Center makes use of multiple models to track hurricanes to increase accuracy of their forecasts, so the energy planner and decision makers can use multiple models to gain a clearer understanding of the energy demand-side sector dynamics. This thesis will use both “top-down” and “bottom-up” approaches in an attempt to distinguish between adoption and diffusion phenomenon as defined in the taxonomy earlier. In the recent years, the dichotomy between the two approaches seem to be fading with the acknowledgement of benefits of both approaches and adoption of hybrid modeling techniques that combine elements and structures from both models.



## Chapter 4 – Technology Adoption Model

### Technology Adoption Model

Technology adoption model describes the actor level decision dynamics that characterize the use or acceptance of demand response technology from each stakeholder's perspective. Some of the key questions this model would help address are:

- Who is the primary beneficiary of demand response technology and what are their needs?
- Who are the secondary beneficiaries of the demand response technology?
- What factors are most important to the stakeholders in embracing demand response technology?
- How do these factors differ across different stakeholders?
- What are the current dynamics and how will they evolve in future?

To answer these questions, it is first necessary to identify the key stakeholders in the demand response sector. A stakeholder analysis for the demand response sector helped unravel the primary and secondary beneficiaries and their needs. The stakeholders in the system are described below:

- The principal beneficiary of the demand response program is the electricity consumer. The primary consumer needs are access to an inexpensive source of energy that is reliable (available continuously all the time), safe and ready for consumption (at specified voltage and frequency) in real time (instantaneous).
- The transmission and distribution (or the grid) owner also referred in this thesis as the utility or retailer is the secondary beneficiary. One of the primary needs of the utility is to transmit and distribute electricity reliably and safely to be sold to customers profitably.
- The generator (power producer) is another secondary beneficiary generating and selling reliable electricity in a cost effective yet profitable manner to the utility.
- The regulator (FERC) is secondary beneficiary ensuring that the society is supplied with reliable electricity in a cost effective manner with minimal environmental impact.

- The Curtailment Service Provider or the DR aggregator is secondary beneficiary aggregating load reductions from customers to ensure grid reliability and cost reduction by providing incentives to consumers and yet operate profitably.

## **Market Dynamics**

To capture the influencing dynamics for market adoption of demand response, an extensive literature review of case studies, empirical results, and pilot program runs of demand response technologies were done. The dynamics that have been proven through statistical means, empirical findings or emerged strongly from survey of leading industry practitioners and academicians have been captured below for building the causal loop relationship between multiple factors.

Although the adoption factors are different from each stakeholder's perspective, many of the factors are common across each of the five stakeholders. Nevertheless, the strength of influence of these factors themselves in the adoption decision varies between different stakeholders. In the interest of brevity, all the key factors influencing the adoption for all stakeholders are consolidated and listed below to avoid repetition of the common factors that influence more than one stakeholder. A detailed discussion of strength of each factor in the adoption dynamics follows this list along with the causal loop diagrams.

In their report "Quantifying Demand Response Benefits in PJM" (Felder & Newell, 2007), the authors arrive at the following conclusion:

1. Demand Response is influenced by the electricity price especially the price at peak load. The higher the price, the higher is the benefit from enabling DR. Program participants receive a lower price than the spot market price by participating in DR.
2. DR events result in wholesale price reduction, thus lowering the overall marginal electricity price due to load shaving in the demand curve and making the load distribution more uniform.
3. In markets with little reserve margin, the impact on market prices is more significant.

In their study (K. Smith & Hledik, 2011), the authors observe the following DR influencing factor and draw the inference that a restructured market structure is correlated with higher levels of DR:

4. The correlation between average price and DR is not present in regulated wholesale markets suggesting a significant impact of market structure on DR adoption.
5. Presence of ISO/RTO (deregulated market) increases DR adoption. The ability for DR to participate in the capacity market is important, as avoided capacity cost is typically the primary financial benefit DR program provides.
6. Retail competition increases DR penetration. Competition enables innovative tariffs and rate structures resulting in attractive benefits for customers able to shed load.
7. In Order 745 Final Rule (Federal Energy Regulatory Commission, Order 745, 2011), the Federal Energy Regulatory Commission passed a ruling that ensures when a demand response resource participating in an organized wholesale energy market administered by a RTO or ISO has the capability to balance supply and demand as an alternative to a generation resource and when dispatch of that demand response resource is cost-effective as determined by the net benefits test described in this rule, that demand response resource is compensated for the service it provides to the energy market at the market price for energy, referred to as the locational marginal price (LMP).

This approach for compensating demand response resources helps to ensure the competitiveness of organized wholesale energy markets and remove barriers to the participation of demand response resources, thus ensuring just and reasonable wholesale rates. LMP clearing price for DR curtailment/resources is a key determinant in adoption of DR.

Authors Smith and Hledik note in “Drivers of Demand Response adoption” (K. Smith & Hledik, 2011) that:

8. The presence of legislative or regulatory policies that directly support DR. A strong DR policy correlated with higher levels of DR.
9. Effect of generation mix on DR is noted. High quantity of hydroelectric generation provides significant peaking capacity. Also, hydropower can inherently acts as energy storage capacity, as operators can adjust the flow of water to the turbines to accommodate changing demand. However, there exists a “tipping point” at which hydroelectric resources can no longer provide adequate flexibility for the system.
10. Increasing fraction of solar and wind power in generation mix requires solutions that can

compensate for unexpected real time variations on the system load. Real time DR could provide the needed reliability to fill in the gap. However, distributed generation and utility scale solar and wind farms introduce volatility in the supply causing increase in the volume risk.

11. Regions with high reserve margin have lower levels of DR. DR is viewed as an option for managing the grid by ISOs and retailers alike. However, the correlation is weak suggesting other stronger factors.

In the report “The Tao of Smart Grid” (Faruqui, 2011), the author notes that:

12. Presence of easily controllable loads is a driver of demand response. Consumer load attributes (e.g. centralized air conditioners, refrigeration, remote lighting controls, etc.) increases ease with which DR can be automated and hence increasing the DR deployment rate.

Lawrence Berkeley National Laboratory study on demand response and smart grid (Chuck Goldman & Roger, 2011) identify that:

13. Peak Load Reduction from Dynamic Pricing by Rate Design and Technology is an enabler of DR adoption.

The MIT study on “The future of electric grid” (MIT Interdisciplinary study, 2011) identifies that:

14. DR could substitute for flexible supply-side regulation service or storage. The value of DR responsiveness is likely to increase with penetration of VERs (Variable Energy Resource) and the importance of loads that may be especially amenable to predictable, quick responses through automated controls, such as air conditioning and charging of electric vehicles.
15. Also as EV penetration increases, direct load control programs (reliability) for charging stations may provide additional targets for enhancing DR potential.

The authors of “What makes a customer price responsive” (Neenan, Boisvert, & Cappers, 2002) find that:

16. High penalties for failure to comply with curtailment requests and uncertain payment tend to discourage DR adoption.

Demand Response participation in restructure markets (Zamikau, 2008) identify the technologies

capable of enhancing DR participation below:

17. Technologies capable of enabling demand response include backup generation, control systems, load monitoring equipment, and energy storage devices.

In the book, “Understanding today’s electricity business” (Shively & Ferrare, 2010), the authors identify the supply and demand factors influencing the generators and electricity market dynamics:

18. The key short term supply/demand factors are

Supply Side:

- a. Units out for maintenance
- b. Fuel availability
- c. Weather impacts on renewables
- d. Transmission line availability
- e. Generation mix – units with long start-up/ramp up times
- f. Environment legislations including tariffs
- g. Availability to import power

Demand Side:

- h. Weather
- i. Business/Economic activity
- j. DR availability

In “A market based model for ISO sponsored DR programs” (V. Smith & Kiesling, 2005), the authors conclude that:

19. A single- sided market with passive, inelastic demand, tends to have higher prices than a market with active demand and supply—a double-sided market.

FERC’s case studies (from pilot programs) identifies the following key drivers of demand response (Federal Energy Regulatory Commission, 2009a):

20. Central air conditioning saturation: The FERC study notes that high central air conditioning market penetration leads to larger demand response potential, because customers with central air conditioning are more responsive to dynamic pricing. Additionally, higher central air

conditioning saturation means that a larger share of the population is eligible to participate in DLC programs.

21. Cost-effectiveness: DR introduction in a market is dependent on the cost-effectiveness. If a program does not pass the economic screen for a given customer class, then it will not be offered to those customers and demand response potential will be lower as a result.
22. Customer mix: States with a higher than average concentration of load in the Residential and large commercial and industrial classes will often have higher demand response potential, as these classes tend to provide the largest per-customer peak reductions.
23. Existing program impacts: As participation in the existing DR programs increases, customers will continue to provide large impacts. Further, a high participation rate in existing programs will contribute to higher overall demand response potential. In particular, the ability of demand response to participate in wholesale markets increases demand response potential.
24. AMI deployment: The DR potential is dependent on the extent and pace of AMI deployment with a higher and faster deployment resulting in larger DR potential.

The above 24 factors are represented in the causal loop structure of market adoption. These models capture the consumer enrollment dynamics in DR programs, the retailer (utility) and ISO DR adoption dynamics, the supply side dynamics of electric power industry, and the CSP growth dynamics. All the variables shared across different models are highlighted in green.

### **Consumer Adoption**

The consumer adoption of demand response is primarily driven by incentive payment and electricity price. Large commercial and industrial consumers have significant energy costs and by curtailing their peak time energy usage they have more to gain. As these large consumers enroll more DR capacity with CSPs, they receive more benefits in the form of capacity and energy payment at a lower consolidated costs resulting in higher DR enrolment rate. This dynamic is represented by the reinforcing loops R1 and R2. Another dynamic shaping the consumer adoption (shaped by reinforcing loop R3) is the bandwagon effect triggered by social factors. It refers to the increased number of consumers enrolling in DR programs due to the social benefits and the pride associated with looking “green” (environmentally conscious).

The penetration of enabling technologies such as advanced metering infrastructure as well as automation of loads such as centralized HVAC that can be automatically controlled are other reinforcing factors enabling a faster adoption of DR. However, as the DR capacity in the wholesale markets increase, it gets increasingly counted as a reliable source of dispatch at times of peak load or peak prices. Increasingly, the consumers realize that they are called more often to curtail their loads that induce a DR overhead in the form of lost opportunity costs and administrative costs. This has a balancing effect on DR adoption and is represented by the loop B2 “DR Fatigue”. Also, as more consumers enroll for DR, the potential capacities available for future enrollment reduces causing market saturation as depicted by the balancing loop B1.

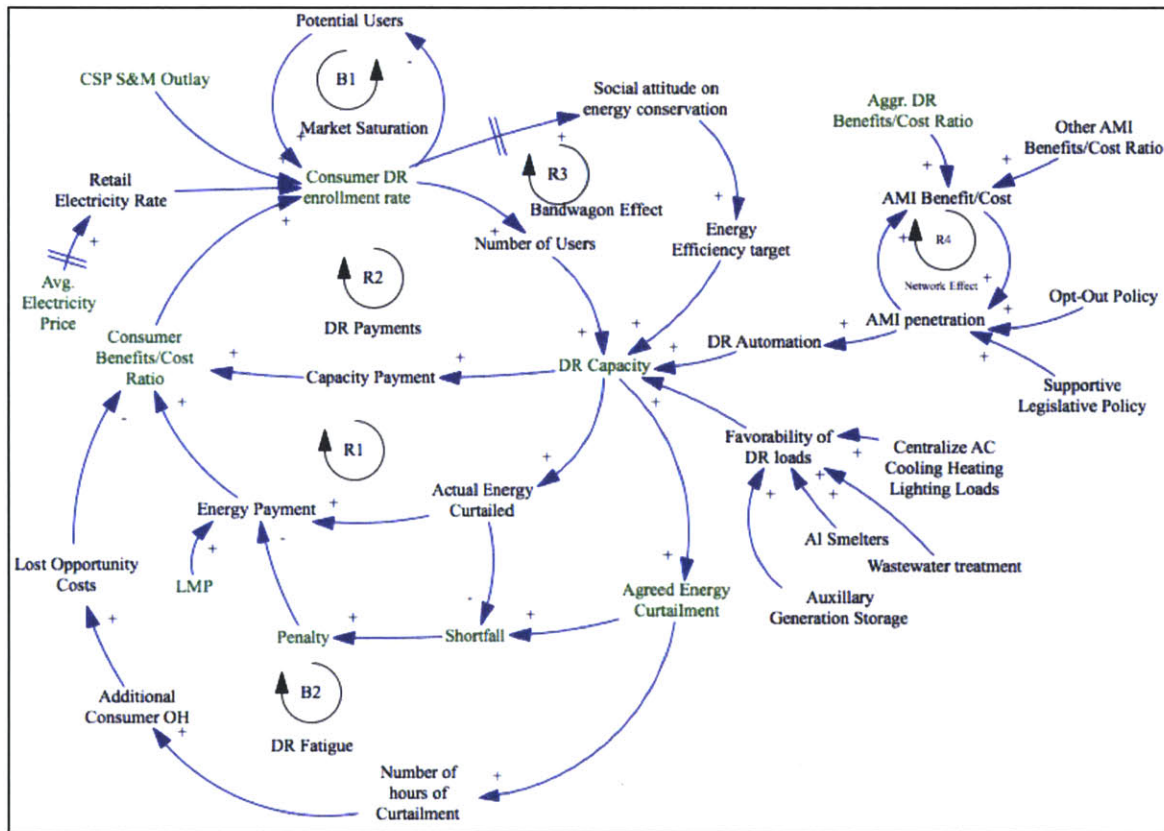


Figure 6 Causal loop diagram explaining dynamics of DR consumer enrollment

## Retailer and ISO Adoption

As the retailer and the independent system operator (ISO) in a deregulated market have closely tied objectives, a single causal loop diagram is used to capture the DR adoption dynamics.

The key measure for DR adoption from ISO or regulators viewpoint is its cost effectiveness, which is a measure of benefits of an investment against cost incurred. Although there are many different measures of cost-effectiveness test and no single one of them evaluates cost-effectiveness from all dimensions, for the purpose of simplicity this thesis will refer to the most widely used net benefit test, namely the Total Resource Cost Test (TRC). The most important question that the TRC test addresses is, whether the total cost of energy in the utility territory decrease by introducing the DR program? To answer this question, it is important to first understand the constituents of the benefits and costs in TRC computation. The below table outlines those constituents.

Benefits and Costs from the Perspective of All Utility Customers (Participants and Non-Participants) in the Utility Service Territory	
Benefits	Costs
<ul style="list-style-type: none"><li>▪ Energy-related costs avoided by the utility</li><li>▪ Capacity-related costs avoided by the utility, including generation, transmission, and distribution</li><li>▪ Additional resource savings (e.g., gas and water if utility is electric)</li><li>▪ Monetized environmental and non-energy benefits (see Section 4.9)</li><li>▪ Applicable tax credits (see text)</li></ul>	<ul style="list-style-type: none"><li>▪ Program overhead costs</li><li>▪ Program installation costs</li><li>▪ Incremental measure costs (whether paid by the customer or the utility)</li></ul>

Source: Standard Practice Manual: Economic Analysis of Demand-Side Programs and Projects.

Figure 7 Benefits and costs included in the Total Resource Cost Test computation<sup>5</sup>

For both the utility and the regulator the TRC effectiveness is the most important factor. As the TRC effectiveness is proven for DR in a particular market and customer class, the ISO adopts DR resulting in higher frequency and amount of power curtailment requested from the system operator (ISO). As the curtailment service provider curtails more loads to meet the ISO requests, it results in higher savings from avoided or deferred investments in transmission and distribution upgrade. The

<sup>5</sup> Source: National Action Plan for Energy Efficiency (2008). *Understanding Cost-Effectiveness of Energy Efficiency Programs: Best Practices, Technical Methods, and Emerging Issues for Policy-Makers*. Energy and Environmental Economics, Inc. and Regulatory Assistance Project.



CSP fulfills the need by acting like a virtual power plant. With more avoided costs and increase in the net benefits, the TRC effectiveness value increases further creating a reinforcing loop depicted by loop R1. In addition to the avoided transmission and distribution costs, another impact of DR is to reduce the peak demand and consequently the short-term supply demand shortfall, which has a direct impact on the location marginal price. This results in reducing the costs of acquiring energy from the spot market for the retailer resulting in higher adoption rates. This dynamic is captured using the reinforcing loop R2. The lower spot prices has the additional effect of lowering the average electricity price in the medium term resulting in a lower futures price in the forward capacity market resulting in further reducing the retailer costs. This additional dynamic is captured through reinforcing loop R4.

As the DR adoption increases across the country, and the TRC effectiveness is acknowledged across different electricity markets, DR attractiveness in other regulated markets also increases. This has the effect of lowering the regulatory risk and consequently the volatility associated with electricity prices arising from fear of regulation. A less volatile market has a downward influence on the spot prices resulting in lower average costs for the retailer and more participation in the DR programs. The “Regulatory Risk Mitigation” loop R3 captures this dynamic.

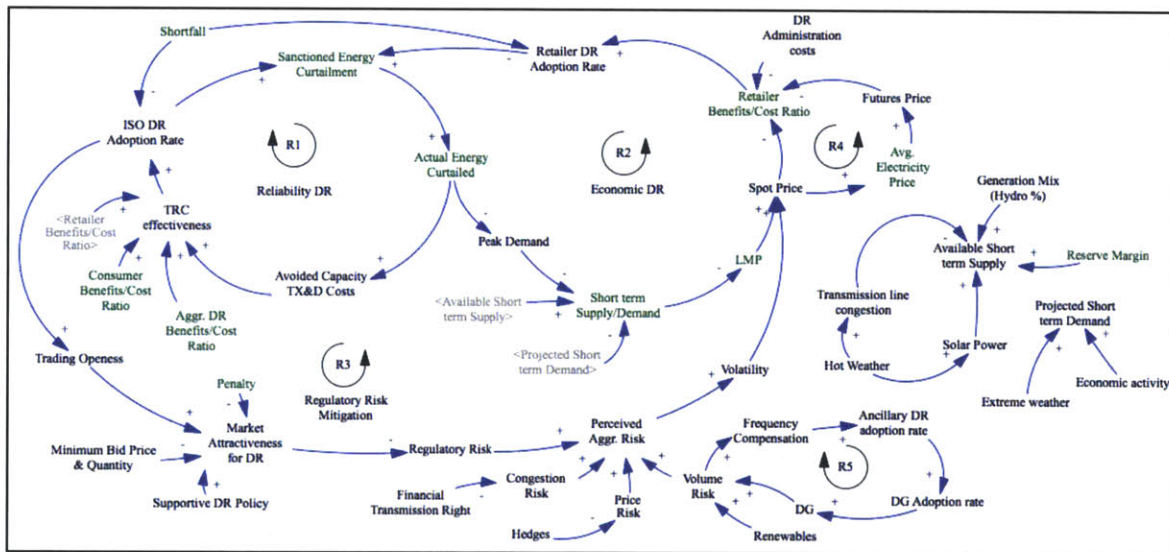


Figure 8 Causal loop diagram explaining DR Retailer and ISO adoption dynamics

### **Power Producer (Generator) Dynamics**

The generator dynamics model is aggregated at the supply-side without distinguishing between the types of power plants, technology in use or the generation mix as the focus of this thesis is on the demand-side technologies. It builds on the work of Vogstad incorporating characteristics such as reserve margin and supply to the demand growth, price elasticity of demand, technological learning curve, and resource depletion dynamics (Vogstad, 2004).

The learning curve of technology is captured through the reinforcing loop R1. As the degree of supply (for a particular technology) in the electricity market increases, cost reductions result from the experience of learning curve attributed to reduction in unit costs as the cumulative production volume increases. Other sources of learning curve improvements that are inherently aggregated in Technological advancement parameter are technological progress, learning-by-doing, and improvement in organizational efficiency. As the investing and operating costs plummet with increasing technological advancements, the expected profitability of investing in that particular technology increases resulting in more capacity. This creates a reinforcing effect on the supply of the particular technology in the electricity market. There are two important delays that need to be accounted for in this dynamic – delay in the investment decision due to policy, financial or regulatory approvals and delay in the capacity addition due to time to construct new power plants.

As the capacity increases for a fixed level of demand, the capacity utilization of the power plant reduces. In contrast to loop R1, this has an impact of reducing the future profitability and thus the capacity stabilization represented through the balancing loop B1. It results in optimizing and stabilizing the capacity factor for a power plant. Likewise, the capacity expansion reaches an equilibrium based on the demand (loop B4), which is dependent on the growth rate and price elasticity of demand. Furthermore, the average electricity price determines the expected profitability of adding new capacity based on the anticipated long-term prices. This has a stabilizing impact on the capacity available in the market and is shaped by the balancing loop B2 in the causal loop. As more fossil fueled based power plants consume fossil fuels, resource availability reduces resulting in increased operation costs and falling interests in investing in new fossil based power plants. This dynamic is captured using the resource depletion-balancing loop B5.

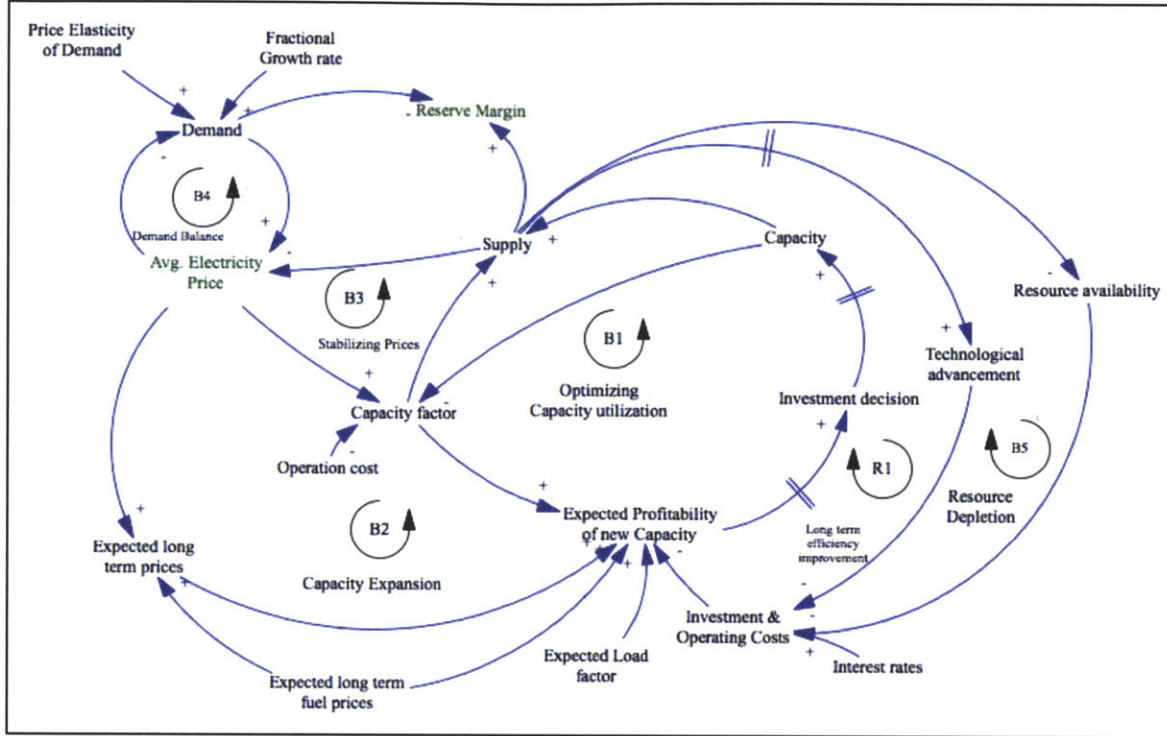


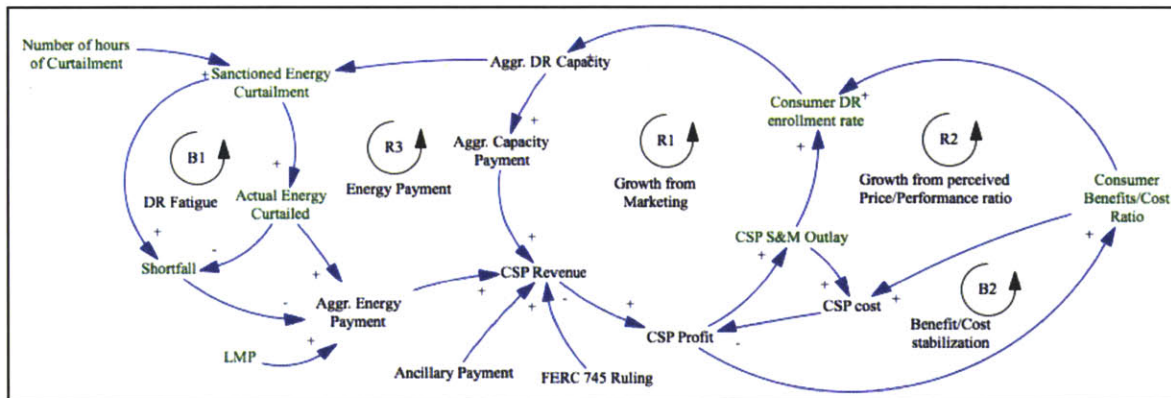
Figure 9 Electric Power Supply Side Causal Loop Diagram

### Curtailement Service Provider (CSP) Adoption

DR providers receive two kinds of incentives – capacity payment and energy payment depending upon the type of DR program. In an energy-only DR program or market, all demand curtailed is compensated based on the price for that kilowatt-hour of electricity. Whereas, in a capacity-based program, participants receive a capacity payment enrolling capacity that can be curtailed on demand and an energy payment for actual load reductions (Enernoc, 2009).

As the aggregate payment to CSP rises with increased DR enrollment, the profit per MW of enrolled capacity also increases as the fixed costs does not change and is spread over more enrolled capacity. The increased profits enables the CSP to spend more on new customer acquisition resulting in increased enrolled capacity creating a reinforcing effect as depicted by loops R1 and R3. As the consumers receive more incentive payments, the perceived benefits also increase leading to more DR enrolment. This reinforcing effect is captured by the loop R2.

With more DR enrolled capacity, DR is perceived as a reliable resource and the CSPs get called more often. As the frequency and loads called to reduce demand surge, customers may encounter a “response fatigue”, or a reduction in willingness or ability to curtail (Charles Goldman, Hopper, Bhavirkar, Neenan, & Cappers, 2007). At a consolidated level, it may result in shortfall against the agreed curtailment capacity. The regulators charge a fine for non-fulfillment, which would lead to decreasing CSP revenue and create a balancing effect on the total DR enrolled capacity. This dynamic is captured by the loop B1 (DR Fatigue).





## Chapter 5 – Technology Diffusion Model

### Causal Loop Diagram and the Key Dynamics

While the bottom-up models reveal finer details of the DR drivers from individual actor perspective, a top down approach captures the changing dynamics at the industry level. The top down model builds on the conceptual model from “The Dynamics of Innovative Industries”(H. Weil, 2005) discussed earlier in the literature review. The dynamics that influence the technology adoption arise from the dynamics of the actors described earlier in the market adoption chapter, hence the sources of the findings would not be listed again but a discussion of it will follow in this section.

The causal loop diagram below shows the main feedback loops that influence the diffusion of demand response technology.

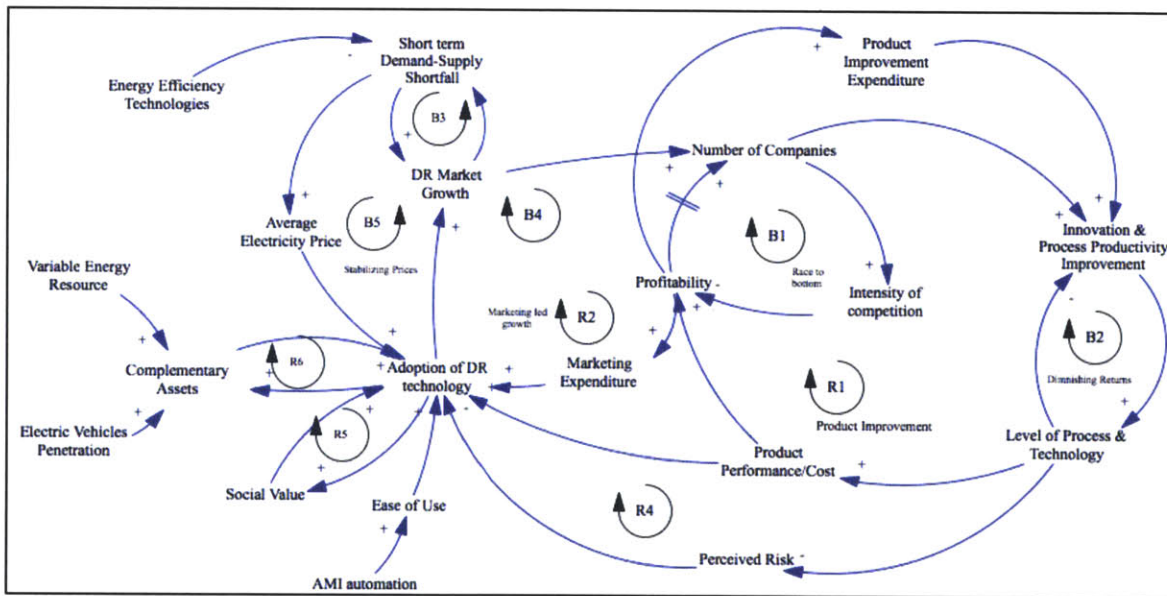


Figure 11 Conceptual model of energy demand side technology diffusion

The key dynamics in this diffusion process are characterized by:

- Growth from product improvement and automation

In the top down causal loop diagram, the growth due to product improvement is illustrated

through the reinforcing loop R1. The CSPs invest in product automation and improvement resulting in improved perception and confidence in the consumer's mind leading to product adoption. The improvement in the level of DR process and technology also drives up the product "Benefits to Cost" ratio resulting in increased profits for the CSP. The CSP invests these profits for further product improvement creating a reinforcing effect.

b) Diminishing returns from product improvement

Initially, increased product improvement expenditure creates a substantial improvement in the product and service over time. At a certain point when the product has considerably improved, it becomes increasingly difficult to improve the product further. The product or service reaches a state of maturity and further investments in product improvement yields diminishing returns. Most products and services go through this cycle of significant improvement in the early stages and diminishing returns as the product matures until it is replaced by a newer platform, technology or innovation. This dynamic is captured by the balancing loop B2 "Diminishing Returns".

c) Marketing led growth

In many industries, the initial adoption of a product or technology happens through the marketing push to build awareness among the potential early adopters. One of the early channels of awareness is through dedicated marketing led campaign such as direct sales efforts, advertising, trade fairs, etc. The loop R2 depicts marketing infused growth. As the marketing outlay increases, more potential adopters become aware of the technology and adopt it. As the DR market grows, the number of firms interested in entering this industry also increases creating further improvements in the product and technology from increased experimentation. The result is increased performance and reduction in unit costs creating a steady and increasing revenue stream for the CSPs. As market matures, the CSPs keep increasing their marketing outlay to build awareness and recruit more consumers, creating a reinforcing effect.

d) Effect of competition

The marketing led growth creates an increasing DR adoption. As the market grows, so does the perception of profitability in the industry. This creates a new wave of capital inducement from

venture capitalists and private equity firms leading to an exponential increase in the number of firms competing in this field. As the intensity of the competition increases, firms try to undercut each other to increase market share. This has an effect of decreasing the overall profitability in the industry and soon firms realize that they no longer can sustain in the business and a shakeout results. This key dynamic has come to become the mainstay characteristics in many industries whenever innovative technologies create discontinuity of technology or service. Some academics have also gone on to note that such patterns characterize the evolution of new industries (Klepper & Graddy, 1990). This dynamic is represented by the balancing loop B1 in the causal loop diagram.

e) Effect of electricity prices

Worldwide, the power sector faces three major challenges: reforms of power markets to encourage competition, requirements to mitigate greenhouse gas emissions, and rising energy prices (Yang & Blyth, 2007). A discussion of the key dynamics is incomplete without acknowledging the impact of these industry specific factors. In this section, impact of energy (or electricity) price will be considered.

The rising energy prices make DR adoption more attractive due to two pronged effect – firstly, consumers receive higher capacity payment for their enrolled capacity as it follows the electricity price in the market and secondly, DR curtailment leads to lower energy use leading to lower electricity costs. Thus, as the energy prices increase, the DR adoptions increase. But, in the long run if energy prices remain steady, then the rising DR market reduces the total peak time shortfall and helping suppress the electricity price. This has an effect of stabilizing the electricity prices as depicted by the balancing loop B5 in the long term if the energy prices remain stable.

f) Influence of complementary technologies

Teece has attributed the emergence of role of complementary assets in technology diffusion to the “Profiting from Innovation” framework. The PFI framework highlighted the influence of complementary asset and defined taxonomy around complementary assets and technologies (Teece, 2006). Weil attributes the influence of complementary assets as one of the factors aiding technology diffusion by illustrating the effect of iTunes platform and accessories

in fueling the growth of iPod(H. Weil, 2007).

In our model, the role of complementary technologies is played by the integration of variable energy resources such as solar and wind energy sources into the grid and by penetration of electric vehicles. These two factors are inherently complementary as one (VER) is a supply side resource where as electric vehicles (EV) are consumption resource. However, both introduce volatility and variability in electric supply and hence require a resource that serves to reduce the volatility. DR could serve as a mechanism to serve as a flexible and balancing resource to better integrate VER and electrical vehicles to the grid(MIT Interdisciplinary Study, 2011). Thus, with larger levels integration of VER and EV, DR adoption is bound to increase. This effect is captured using the reinforcing loop R6 in the causal loop diagram.

g) Effect of social value

Worldwide, climate change concerns are growing and gaining increased support from governments, NGOs and the public at large. A Demand-Side Management study reveals that DR can help reduce carbon emissions by 115 million tons by 2030(Faruqui, Wikler, & Bran, 2002). DR as a resource that reduces greenhouse gas emissions becomes especially important to large industrials and commercial customers seeking to reduce their carbon footprint. As the social consciousness for emissions reduction gains more support the DR adoption would grow which in turn builds the public perception and expectation for further emission reduction. This dynamic is captured through the reinforcing loop R5 in the causal loop diagram.

### **Stock and Flow Representation of Technology Diffusion Model**

A major issue in modeling is determining what aspects of the system are endogenous and which ones exogenous. Not only is it difficult to make decisions about this distinction, but also it is a challenge to communicate this issue with all the stakeholders involved. A system boundary helps in scoping the problem and therefore clearly delineates the modeling space.

Defining the boundary of a system, while seemingly simple, presents a challenge to many modelers. One approach to solve this difficulty would be to establish a clear context. Establishing the context starts with understanding the endogenous and exogenous parameters. Both these parameters should



be modeled differently. A boundary establishes the entities that are inside and outside the system. In the model used in this work, the endogenous parameters are modeled using system dynamics approach while the exogenous influence is simulated through scenario analysis.

The system dynamics model settings and characteristics are listed below:

**Model scope:** Demand Response Technology Diffusion Model

**Sector:** Electric Power demand side technologies

**Market:** Restructured US electric power reserve market

**Approach:** Top-Down, Descriptive

**Time Horizon:** Long (Time Horizon = 20 years)

**Supply side Sources:** All the supply-side sources are aggregated at the electricity market level for the important parameters such as costs, capacity, demand, capacity factor, reserve margin, volatility, LMP, etc.

**Demand side Sources:** Demand Response (DR), Energy Efficiency (EE), and Distributed Generation (DG)

**Perspectives:** Demand Response Contextual Industry Dynamics

**Policy scope:** FERC regulatory measures (e.g. FERC order 745, 1000)

**Geographical Area:** USA (De-regulated markets, in general it can be applied to any restructured market across the world by localizing the policy instruments and the dataset)

**Subsystems:** Wholesale Electricity market, Demand Response adoption models from the perspective of Consumer, ISO, Retailer, and Curtailment Service Provider (CSP)

The stock and flow system dynamics model arrived at in this thesis focuses on long-term diffusion of demand-side technologies. The model captures both the structural dynamics as well as the behavioral dynamics.

NOTE: The parts highlighted in green are the dynamics that are influenced by factors outside the DR sector spectrum whereas the arrows highlighted in blue are the dynamics influenced by factors intrinsic to DR sector. All table functions are prefixed with TB. All formulae and description of variables are listed in the appendix.

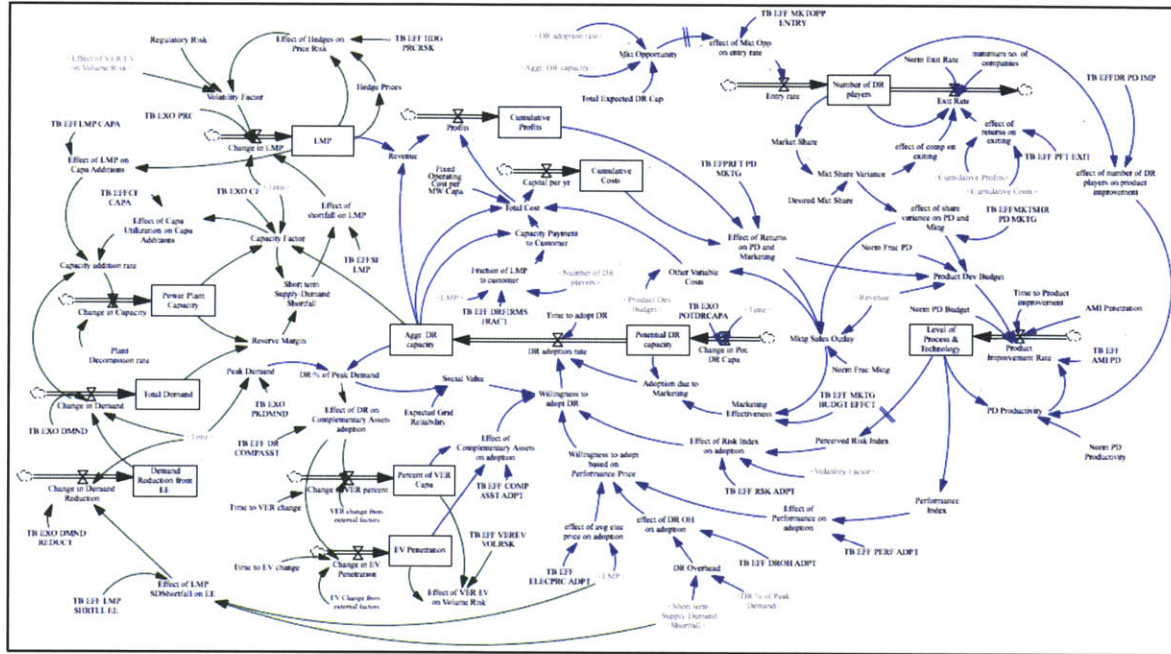


Figure 12 System Dynamics Model illustrating Technology Diffusion of Demand Response

The causal links and feedback structures have already been discussed earlier in the top down causal loop diagram. This section will partition the major subsystems of the system dynamics models and discuss the sub-structures to impart more clarity.

## Financial Structure

Before we discuss the different elements of the financial structure in the DR sector, it is important to delve into the exogenous elements of the sub-system. The build up of potential DR capacity is modeled based on a consolidated set of exogenous factors. The various constituents that make up this table are discussed in detail in the scenario analysis section. As the adoption rate increases, the aggregate DR capacity builds up while the potential DR capacity depletes. The revenue earned by the CSP is modeled based on the capacity payments that it receives from the electricity spot market. The main component of costs are the fixed operating costs, the variable costs based on the respective capacity enrollments of each customer, and other variable costs composed of product development and marketing outlays. The major component among all three constituents is the variable costs associated with capacity payments to the consumer for their enrollment. It is directly dependent on the capacity price in the market and the consumer's share of capacity payment, which

is a function of the effect of competition. The key variables that influence the DR financial structure are the aggregate DR capacity, and the capacity price in the electricity spot market; the former dependent on the total DR market capacity, which is function of other exogenous factors.

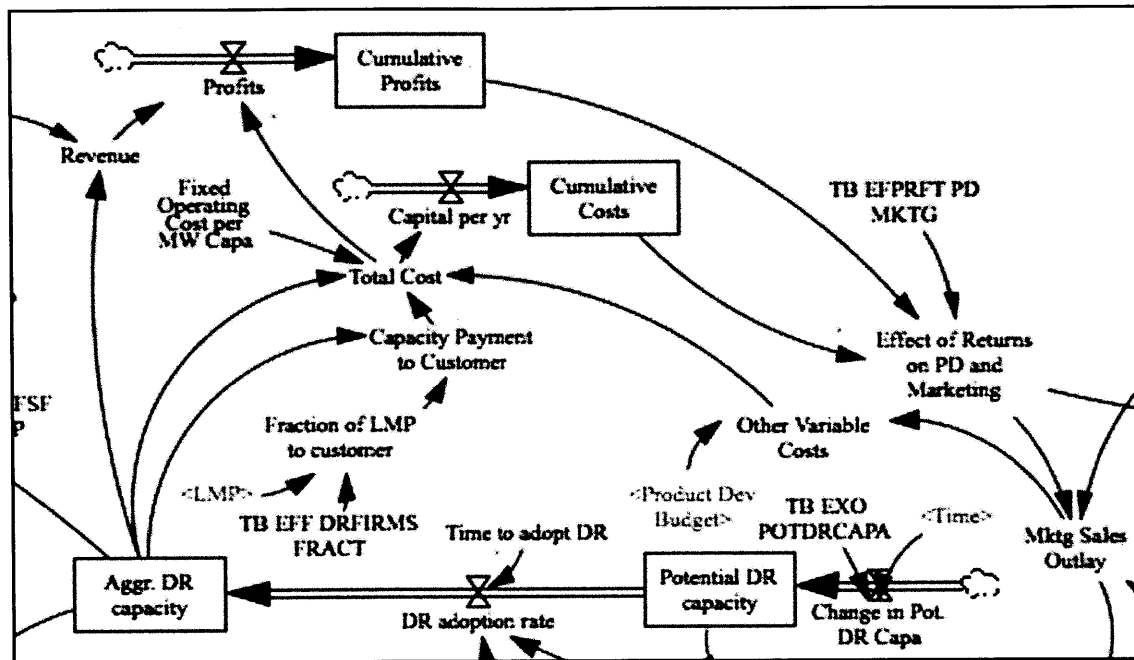


Figure 13 Financial Structure of SD Model

## Behavioral Dynamics

Sterman discusses a vivid example of how queuing theory could be used to model a queue in a supermarket. He notes that a quintessential flaw in this approach is with the assumption that the rate of arrival of people joining a queue is exogenous. In reality, people actually choose to enter the line based on their estimate of expected waiting time. Omitting such behavioral elements from the model in the interests of analytical tractability will often lead to fatal policy conclusions (Sterman, 2000). To overcome this shortcoming and capture the important dynamics of the system in its entirety, we incorporate the relevant behavioral dynamics into our model.

The DR adoption rate can be classified as broadly dependent on two factors – external and behavioral influences. The external influence is modeled based on the Bass diffusion model which

assumes the potential adopters become aware of innovation through external information sources whose effect is roughly constant over time (Bass, Krishnan, & Jain, 1994).

The behavioral dimension of the model is arrived at after thorough analysis of literature on DR pilot programs and surveys as discussed previously in the chapter on market adoption model. The variable “willingness to adopt DR” represents the accumulated behavioral weight for DR adoption. Willingness to adopt DR can be further broken down to three key factors, namely – Performance-Price dimension, Risk perception and social and complementary factors. Out of these, the performance-price dimension is the strongest and is comprised of effect of electricity price on DR adoption, effect of performance of DR technology and effect of DR overhead on DR adoption. Among these, the former two have an enhancing effect on DR adoption while effect of DR overhead has an opposing effect. The effect of price is more pronounced and hence assigned more weight than rest of the factors. Risk Index is based upon the perceived technological risk and the volatility factor, which again is a weighted computation of volume risk, price risk and regulatory risk. The perceived risk is modeled as an informational delay of inverse of technology maturation level. Lastly, effect of social value and complementary technologies depend on the expectation for grid reliability, energy savings from energy efficiency measures, and the penetration of variable energy resources and electric vehicles. These dynamics have been discussed in detail in the technology diffusion causal loop diagram. The influence of each of these behavioral dynamics is modeled endogenously with their respective weightage based on table functions. A discussion of these weights follows in the sensitivity analyses section.

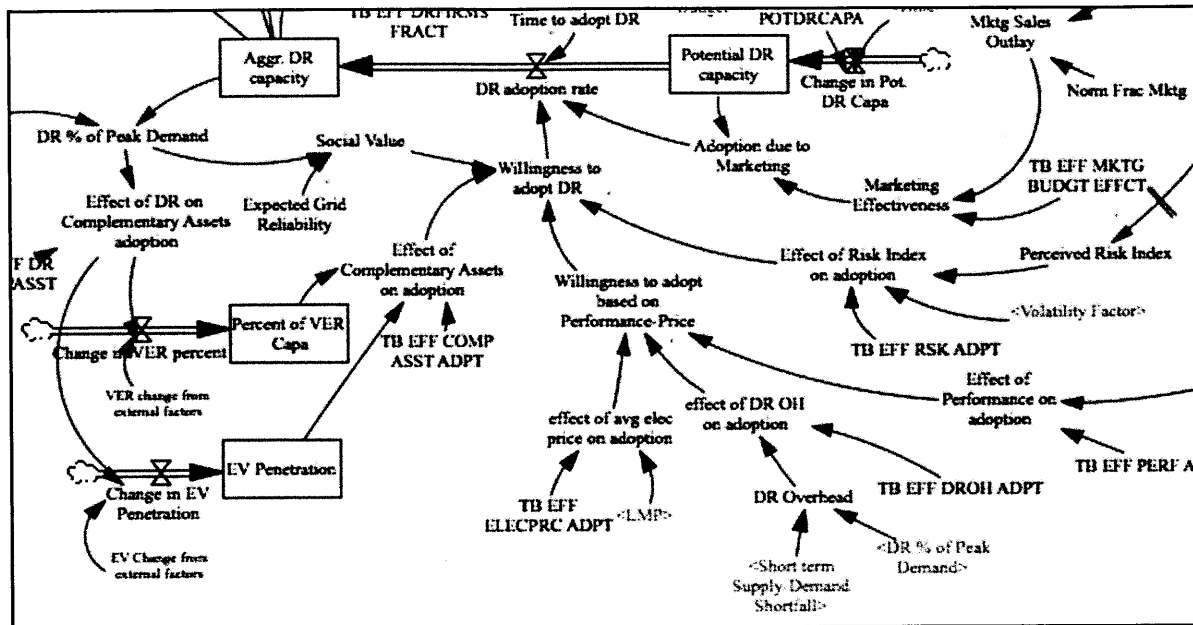


Figure 14 Behavioral Structure of the SD Model

### Competition and Product Improvement Structure

The effect of competition on product improvement rate cannot be dissociated and hence these two factors are represented below as part of one subsystem. As the market opportunity grows based on potential and aggregate DR capacity, the number of firms entering into DR sector increases as well. An upsurge in the number of DR firms leads to increased experimentation and larger product development budget leading to acceleration of product improvement or service levels. At the same time, as more firms enter into DR space, the individual market share that each firm targeted would not be achieved. Failure to meet these market share and profitability targets leads to acceleration in the exit rate of companies, eventually culminating in a shakeout. In addition, as the product or service reaches a state of maturity, further investments in product improvement yields diminishing returns. The effect of market share variance on product development is modeled such that the fractional budget for product development increases if the firm does not meet its desired target share.

Many models simulate technological progress and learning exogenously. In such models, technology is assumed to improve steadily at a constant rate with time and installed capacity. The source of

technological improvement could be attributed to technological progress, learn-by-doing, reduction in input or financing costs, or improvement in organizational efficiency. However, such models neither distinguish the source of learning nor does it disentangle the cost reductions arising from learning effects to those arising from economies of scale and scope (Kumbaroğlu, Madlener, & Demirel, 2008). If the effects from multiple sources are not appropriately accounted for, then it could lead to inaccurate learning rates. In our model, we internalize the process of technological learning by factoring in the effect from competition, increased experimentation, product development budget, and influence of installed capacity. This ensues a deeper understanding of the technology diffusion process by attributing the effect to the cause.

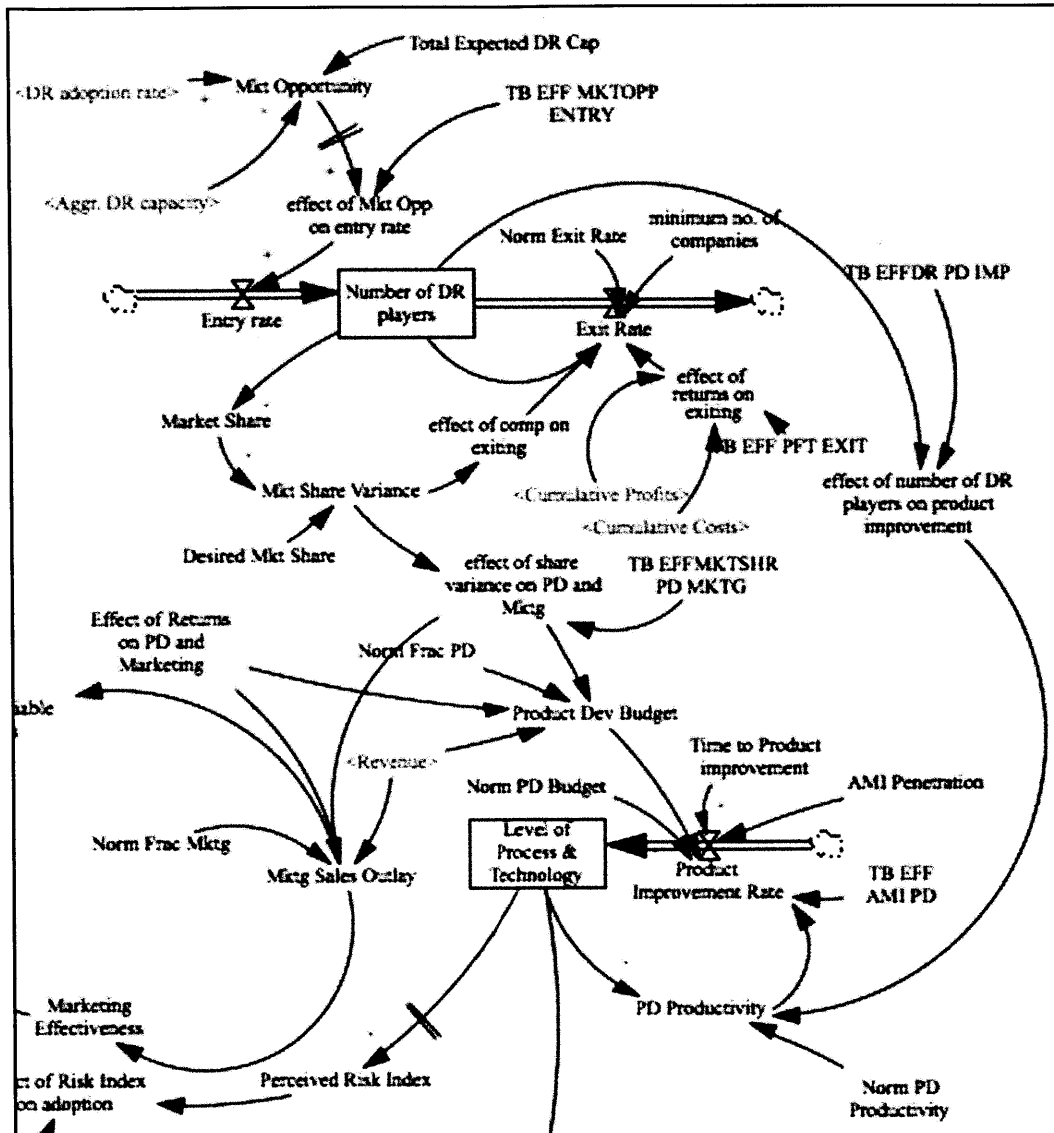


Figure 15 Competition and Product Development Structure of the SD Model

### Electricity Market and Complementary Technologies Structure

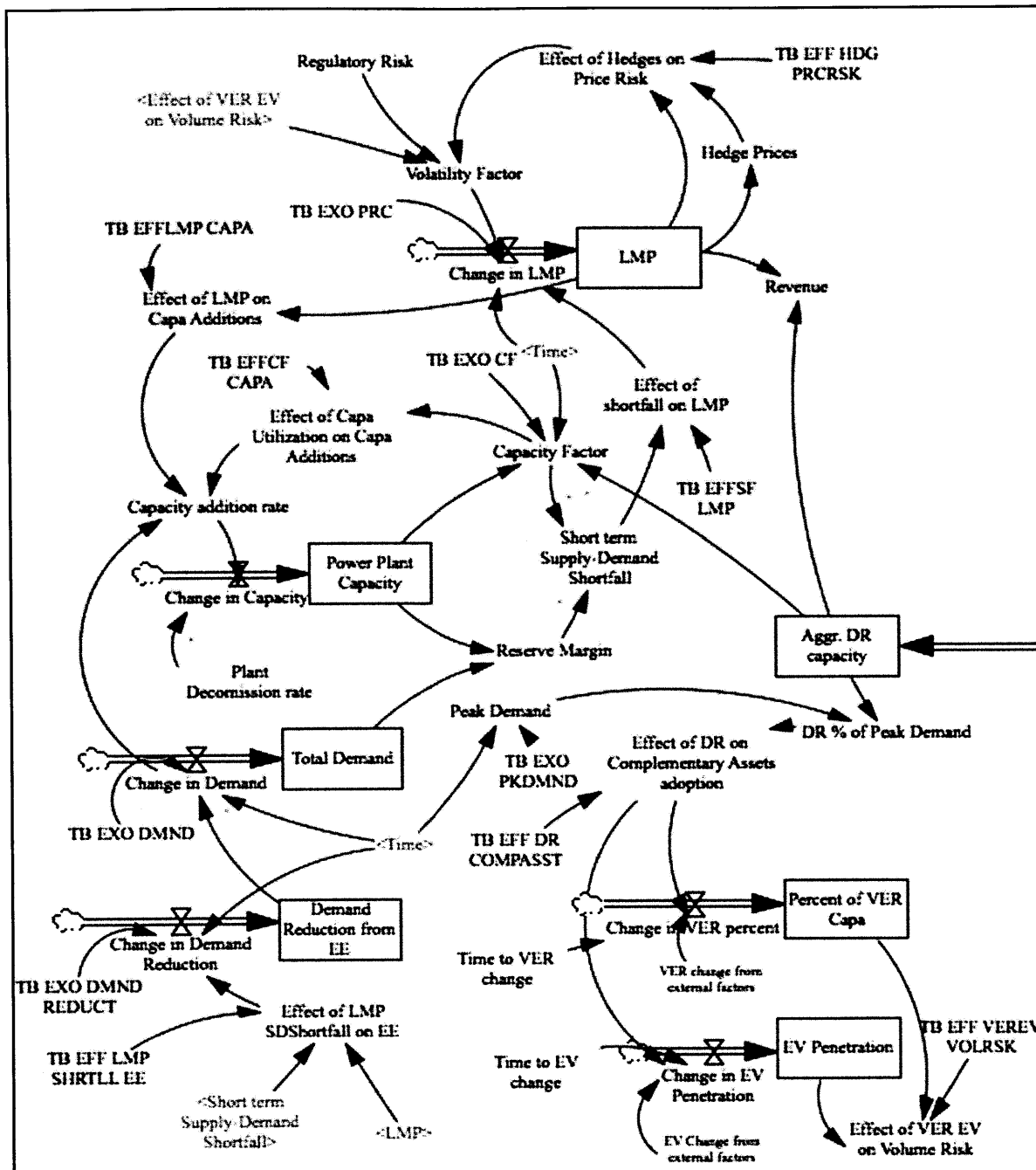
Although the DR is a demand side technology, any energy demand-side systems model cannot be complete without accounting for supply side dynamics. The supply side is aggregated at the system level without differentiating across resource mix. The key variables of interest in this electricity market structure are the total capacity, demand, capacity price, reserve margin and the capacity factor.

The reserve margin is the total supply capacity in a region. Capacity factor is defined as the ratio of the electrical energy produced by a generating unit for the period of time considered to the electrical energy that could have been produced at continuous full power operation during the same period(EIA, n.d.). The capacity factor used in the model adjusts for changes in demand and capacity due to the addition of aggregate DR capacity. The formulae for these variables are listed in the appendix.

Hedge price is formulated as first order informational delay of LMP. Volatility factor aggregates the impact of various risks – price risk from volatility in the spot market, regulatory risk based on the uncertainty in policies and legislation, and lastly the volume risk to account for variability in supply from increasing integration of variable energy resources and variability in demand to account for penetration of electric vehicles. Note that these risks can be mutually independent and hence the effect of these risks is summed. The LMP is formulated based on the impact of the abovementioned risks and an exogenous forecast of LMP, which closely follows the market forecasts. The LMP assumptions are put to test through sensitivity analysis discussed in the next chapters.

Complementary assets and technologies to DR that are considered in the model include the variable energy resources and the electric vehicles. As discussed previously, DR could serve as a flexible resource to balance the impact on the grid due to higher integration of VER and increased penetration of EV. Another technology that complements DR on one plane and competes with it in another dimension is energy efficiency solutions. While increased adoption of energy efficiency measures obligates the need for DR, it complements DR by helping automate DR through efficiency enhancing automation controls. Two factors that influence energy efficiency measures endogenously are the short-term supply-demand shortfall and the LMP. Energy efficiency solutions directly serve to reduce the demand. In our model, the energy efficiency data, the power plant capacity and the total demand are based on the actual records and forecasts from the EIA database.





## **Model Data and Assumptions**

In this section some of the crucial assumptions and source of data is listed. The assumptions pertain to the model and not the methodology or its applicability itself.

The historic records (2000-2010) and forecasts (2011-2019) for the annual total capacity, demand, energy efficiency savings, prices, and peak load reductions in USA are sourced from the eGRID and the EIA database (<http://www.eia.gov/electricity/annual/>). The LMP value reflects the capacity payment and not the energy payment value.

Some factors such as the interruptible rates, favorability of loads (such as centralized HVACs) for DR adoption is accounted for directly in the potential DR capacity calculated by FERC in its forecast and assessment report and hence not modeled explicitly in our model. These forecasts for potential DR capacity are then used as exogenous inputs in our model and analyzed based on scenarios. The scenario specific dataset is described in the model results and scenario analyses section in the next chapter.

The model assumes that the FERC's DR assessment report accounts for the uncertainty in policy and regulatory measures by internalizing them into dynamic pricing tariffs and the Advanced Metering Infrastructure (AMI) penetration. For example, if the regulatory and policy measures were favorable, then it would indicate an increased enrollment into dynamic pricing schemes and a higher AMI penetration. The percentage enrollment into dynamic pricing schemes and the AMI penetration are varied under different scenarios and discussed in detail in the scenario analyses section.

## **Chapter 6 – Model Results, Sensitivity Analyses and Scenario Analyses**

### **Sensitivity Analyses**

Although most of the datasets used in the model is based on actual historic data, it is important to note that some of the data used in the model are either projections derived from EIA database and FERC reports or close approximations in very few cases when reliable data could not be sourced. Thus, it is imperative that we test these projections to see how sensitive the model results are to the assumptions. Sensitivity analysis is a methodology used to understand how the model results and dynamics vary with changes in the model parameters. Sterman notes multiple advantages of performing sensitivity analysis in the business dynamics book. Sensitivity analysis not only “helps develop a good intuition regarding the relationship between structure and behavior of complex dynamic systems, it also helps test the robustness of conclusions with respect to uncertainty in the estimated parameters”(Sterman, 2000). He further highlights the use of sensitivity analysis to guide the data collection efforts. Parameters that influence the results dramatically should have accurate data whereas those parameters that have little effect on the results need only be approximated. Sensitivity analyses further help us identify the leverage points in the system for policy or decision maker intervention.

Although a detailed multivariate sensitivity analysis can be readily generated through the Vensim® Professional tool, in this thesis we use illustrative runs to highlight the sensitivity of the model results to key variables owing to lack of easy access to the professional version of the tool. Scenario analysis discussed in later sections account for multivariate uncertainties based on probable outcomes. The following univariate sensitivities would be analyzed in this section:

#### **1. Impact of DR Overhead**

One key question that often comes up in the DR sector is “as the frequency of curtailment requests increases, would consumer response to price signal be persistent over time or will “response fatigue” set in and erode the DR levels”(Federal Energy Regulatory Commission, 2009b). To investigate the effect of DR fatigue, the influence of DR overhead on willingness to

adopt DR was amplified by a factor of two. If the DR fatigue effects were pronounced then the aggregate DR capacity would reduce or slow down. If this were the case, then a more detailed model of DR fatigue would be of interest to understand the factors (and scale of) that influence the fatigue.

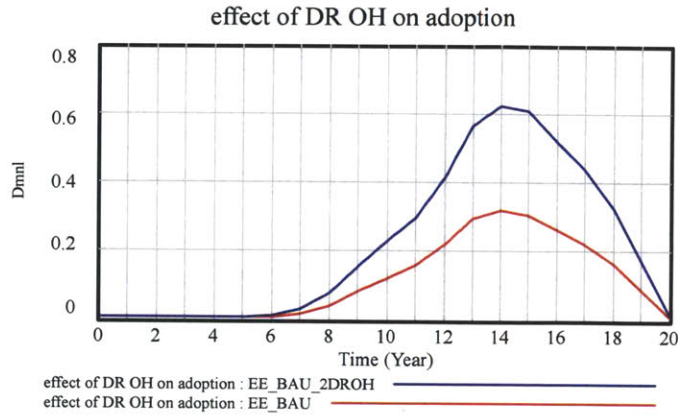


Figure 17 Effect of DR OH plot 1

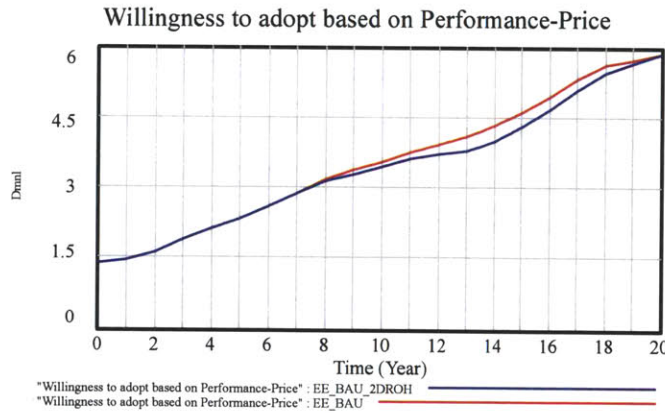


Figure 18 Effect of DR OH plot 2

The sensitivity influence of DR overhead revealed only a marginal change in the aggregate DR capacity as illustrated below. Thus, it turns out that DR overhead is not as big a driver when compared to effect of price on DR adoption leading us to infer that a more detailed data gathering and modeling of DR overhead would only marginally improve our model. However, the importance of DR overhead should not be ruled out from a CSP perspective, hence we would return to a discussion on the topic in scenario analysis and results sections.

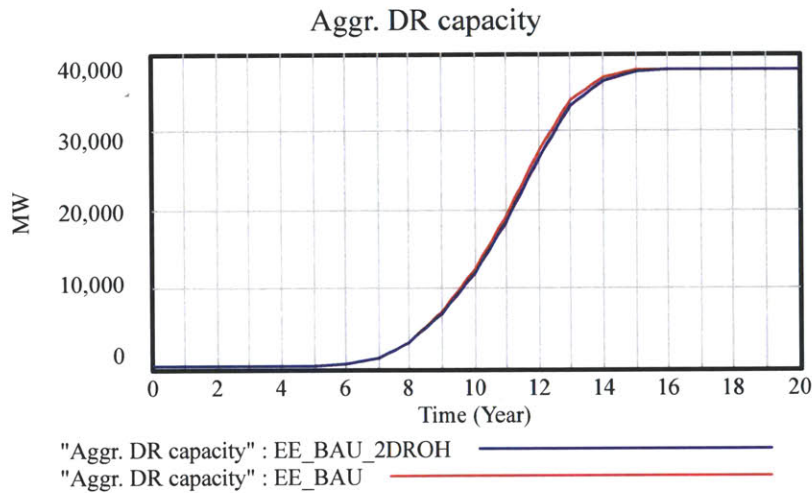


Figure 19 Effect of DR OH plot 3

## 2. Impact from Regulatory risk

Policies that increase risk of return on investment for CSPs or dent the consumer confidence in the stability of DR contracts with CSPs have a negative impact on DR adoption. A sensitivity analysis on aggregate DR capacity by increasing the regulatory risk index to 4.0 resulted in a delay of over 2 years in the uptake of DR adoption. This effect could be explained by the increased risk that consumers perceive in stability of DR contracts as a result of changing policy landscape. FERC ruling 745 helped “even the playing field” for CSPs by requiring the operators to pay DR resources the locational marginal price. The subsequent tentative acceptance of docket ER11-3322-000 requires companies participating in Demand Response programs be not compensated above their Peak Load Contribution. Although this further “levels the playing field” from the regulators perspective, it provides little advantage to companies aggregating large DR capacities and as a result could potentially reduce the profit margins for the large CSPs that have aggregated large capacities. As Luke McAuliffe in his post explains that capacity in some markets is acquired years in advance and consequently the CSPs may have made commitments based on an assumption that they could count reductions from actual load levels above the Peak Load Contribution as part of their performance (McAuliffe, 2011). Such regulatory changes increase the risks of DR adoption and could stub the aggregated DR capacity momentarily. However, in the long term as the impact of such regulatory changes become clearer, the market will catch up based

on the anticipated profitability. The said dynamic is captured in the below plot illustrating the decelerated growth in aggregate DR capacity, but reaching the full potential eventually, provided the additional DR capacity can be acquired profitably.

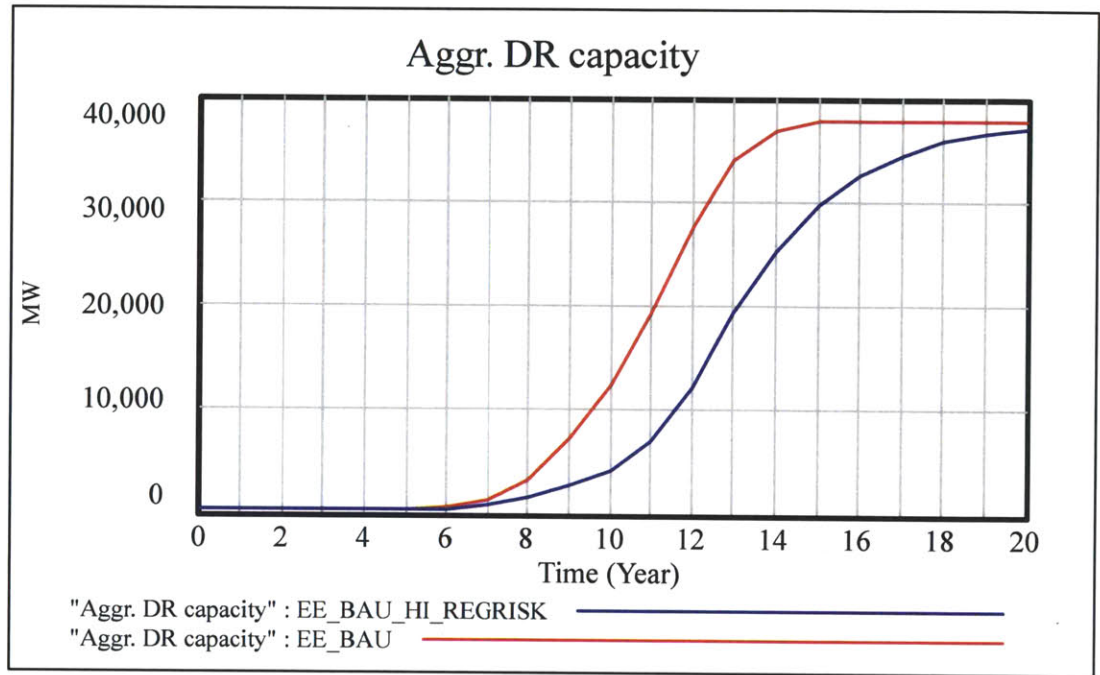


Figure 20 Impact from Regulatory Risk

### 3. Effect of Locational Marginal Price

In our base case BAU, the Locational Marginal Price (LMP) growth projections use conservative estimates when compared to the actual rates in the deregulated market. Thus, it is important that the effect of LMP on DR adoption is investigated. If the rate of change of LMP is doubled, then the DR adoption is quicker due to the increased willingness to adopt. This increased willingness to adopt can be rationalized by a firm's necessity to reduce costs and capitalize on increased savings from DR capacity in the face of high-energy prices.

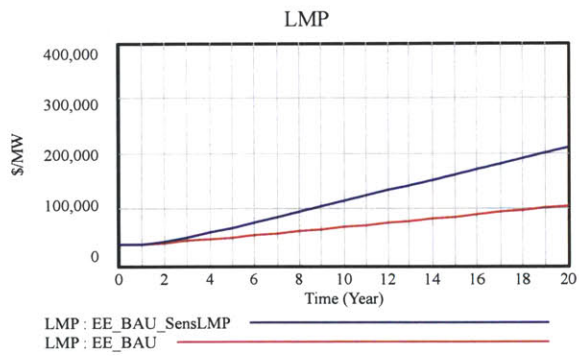


Figure 21 Effect of LMP plot 1

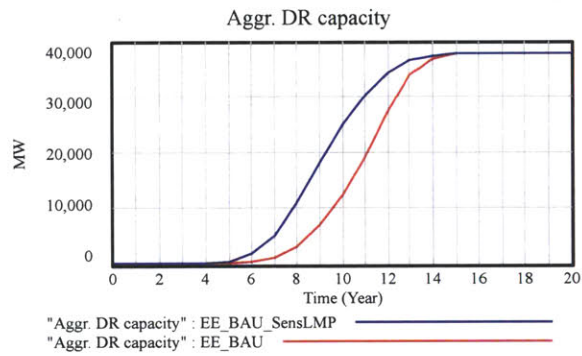


Figure 22 Effect of LMP plot 2

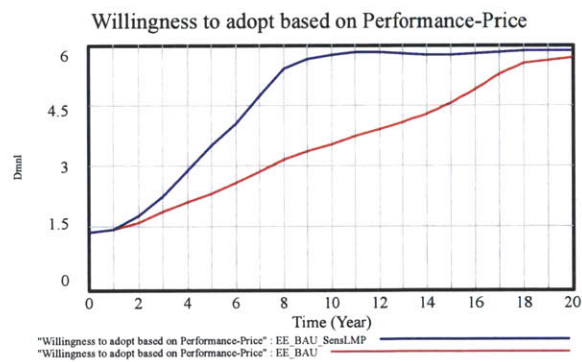


Figure 23 Effect of LMP plot 3



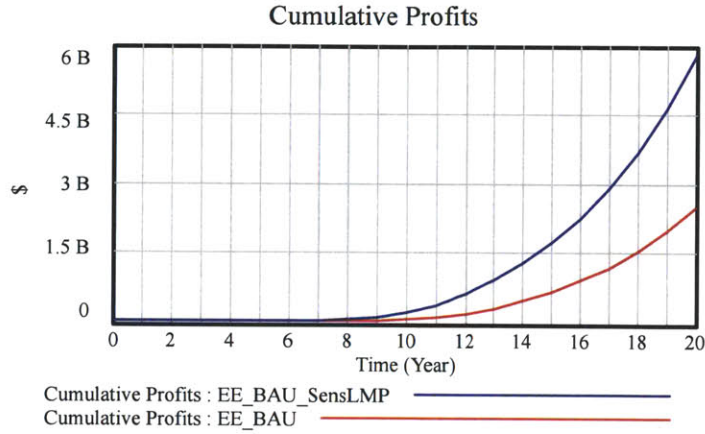


Figure 24 Effect of LMP plot 4

Although LMP has a significant influence on the DR adoption, its effect is unidirectional, that is, as the LMP increases it results to quicker and earlier DR adoption. Nevertheless, due to its more pronounced effect compared to other parameters, LMP values are calibrated to closely follow the market values based on historic projections.

### Scenario Generation

The model was calibrated with the dataset for Business-As-Usual (BAU) scenario and simulated. For the purpose of brevity, the model results will be discussed and compared in tandem with other scenarios instead of devoting a separate chapter for it. All the dynamics of the system would be covered for the baseline (BAU) scenario for the sake of clarity and completeness.

Traditionally businesses have approached uncertainty in two ways— either acknowledging it by applying powerful analytical frameworks or planning processes that use point forecasts to bury uncertainty in their cash flow analysis (Courtney, Kirkland, & Viguerie, 1997). Scenario analysis presents a framework to systematically deal with uncertainty by evaluating the (mental or system) models against a range of scenarios and the implications that arise from it to inform decision-making. Although no approach can overcome uncertainty, it fosters improved decision-making by accounting for foreseeable alternative futures.



Scenario specification is the first step in policy design and evaluation activity of a modeling process(Sterman, 2000). We will consider wide range of alternative scenarios to evaluate our model that can be used for policy guidance and assist decision-making.

FERC study elaborates on different Demand Response potential scenarios namely - Business-As-Usual (BAU), Expanded Business-As-Usual (EBAU), Achievable Participation (AP) and Full Participation (FP). These different scenarios represent increasing levels of Demand Response Penetration as laid out in the figure below. We will discuss the different technological, economic and policy constituents of each of these scenario in detail:

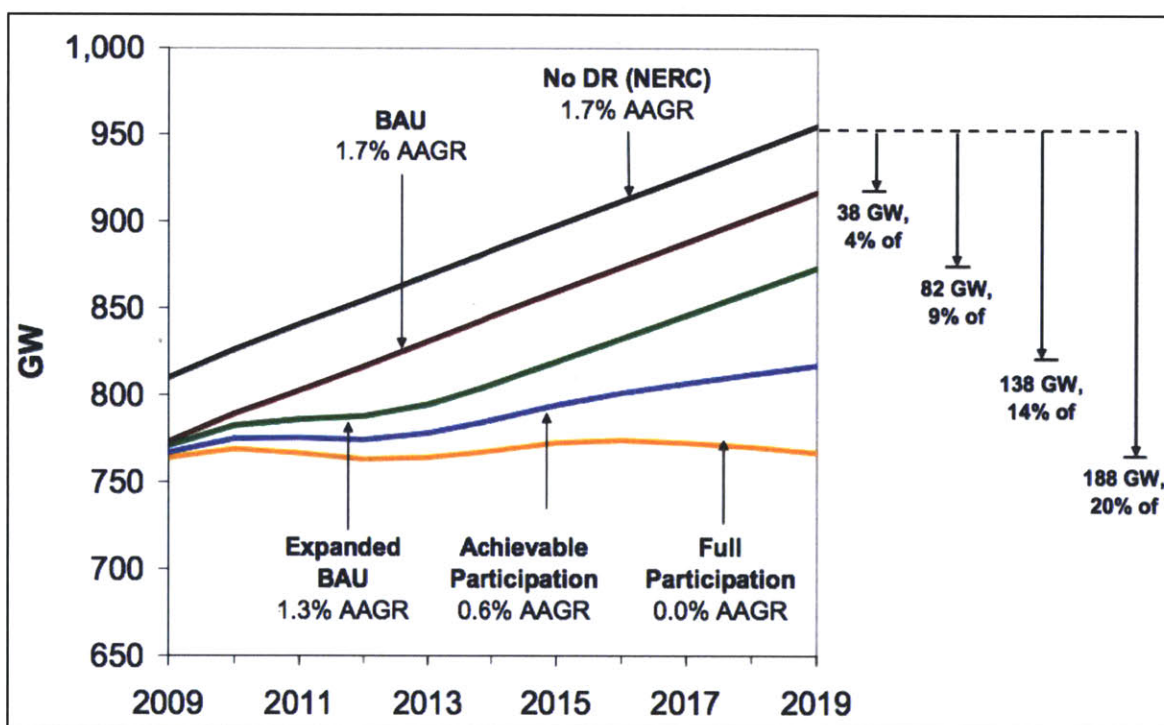


Figure 25 Scenarios<sup>6</sup>

### Business-As-Usual Scenario (BAU)

FERC defines the Business-as-Usual scenario as “the amount of demand response that would take place if existing and currently planned demand response programs continued unchanged from 2010

<sup>6</sup> Source: (Federal Energy Regulatory Commission, 2009a)

to 2019. Such programs include interruptible rates and curtailable loads for Medium and Large commercial and industrial customers, as well as direct load control of large electrical appliances and equipment, such as central air conditioning, of Residential and Small commercial and industrial consumers”(Federal Energy Regulatory Commission, 2009a). The favorability of loads (such as centralized HVACs) is accounted for directly in the potential DR capacity.

The reduction in peak demand under this scenario is 38 GW by 2019, representing a four percent reduction in peak demand for 2019 compared to a scenario with no demand response programs.

#### **Expanded Business-as-Usual Scenario (EBAU)**

FERC expresses the Expanded Business-as-Usual scenario as the “Business-as-Usual scenario with the following additions: 1) the current mix of demand response programs is expanded to all states, with higher levels of participation; 2) partial deployment of advanced metering infrastructure; and 3) the availability of dynamic pricing to customers, with a small number of customers (5 percent) choosing dynamic pricing” (Federal Energy Regulatory Commission, 2009a).

The reduction in peak demand under this scenario is 82 GW by 2019, representing a 9 percent reduction in peak demand for 2019 compared to a scenario with no demand response programs.

#### **Achievable Participation Scenario (AP)**

FERC defines the Achievable Participation scenario as an estimate of demand response penetration if 1) advanced metering infrastructure were universally deployed by 2019; 2) a dynamic pricing tariff were the default and between 60 to 75 percent of customers stay on dynamic pricing rates; and 3) other demand response programs, such as direct load control, were available to those who decide to opt out of dynamic pricing. In addition, it assumes that, 60 percent of customers who are on dynamic pricing rates will use enabling technologies such as programmable communicating thermostats (Federal Energy Regulatory Commission, 2009a).

The reduction in peak demand under this scenario is 138 GW by 2019, representing a 14 percent reduction in peak demand for 2019 compared to a scenario with no demand response programs.

#### **Full Participation Scenario (FP)**

FERC classifies the Full Participation scenario as Achievable Participation with 100 percent of customers on dynamic pricing rates and use enabling technology (Federal Energy Regulatory Commission, 2009a).

The reduction in peak demand under this scenario is 188 GW by 2019, representing a 20 percent reduction in peak demand for 2019 compared to a scenario with no demand response programs.

Before we debate which of these scenarios to use for our system dynamics model analysis, it is important to understand the different measures of potential namely – theoretical potential, technical potential, economic potential and developable potential.

IEA defines theoretical potential by the physical limits of use and thus marks the upper limit of the theoretically realizable contribution. The technical potential is described as the fraction of the theoretical potential that can be used under the existing technical restrictions. The economic potential describes the context (time and location) dependent fraction of the technical potential that can be economically utilized within the actually considered system. The economically developable potential, the smallest of the four, describes the fraction of the economic potential that can be developed under realistic conditions(Rybach, 2009).

The full participation scenario measures potential way beyond the economically developable potential and it has little relevance in assessing the practical deployment of demand response. Although the full participation scenario can be useful for scenario analysis, since the purpose of this thesis is to understand the dynamics shaping the industry rather than on forecasting the future, we omit the full participation scenario from our analysis. For the remaining scenarios (BAU, EBAU and AP) the data is sourced from the FERC commission report.

#### **Business-As-Usual Scenario without Energy Efficiency (BAU\_WOEE)**

We also framed scenarios with and without energy efficiency measures to compare and contrast the impact of energy efficiency technologies and policies on demand response potential and diffusion. The default scenario is generated with energy efficiency considered in the projections and is referred to as EE\_BAU, whereas the scenario without accounting for energy efficiency measures is referred to as BAU\_WOEE.

#### **Business-As-Usual Scenario with Increased VER & EV Penetration (BAU\_INCR\_VER\_EV)**

An energy policy driven by climate change concerns and to some extent from energy security perspective could influence increased adoption of renewable energy technologies and less polluting

transport options such as electric vehicles. To test the impact of policies that increase the penetration of variable energy resources (VER) and electric vehicles (EV) on demand response potential and diffusion, a scenario analysis was performed. The scenario results are denoted by BAU\_INCR\_VER\_EV in the plots.

All the scenarios discussed above are summarized below alongside scenario constituents:

Scenario	AMI Deployment	% Customers in Dynamic Pricing	Dynamic Tariff	DR Capacity (in GW)	% Peak Demand Reduction	Energy Efficiency Measures Considered	VER & EV Penetration %
Business As Usual (BAU)	Fractional	0%	Optional	38	4	Yes	0.3
Extended Business As Usual (EBAU)	Partial	5%	Optional	82	9	Yes	0.3
Achievable Participation (AP)	Full	60-75%	Default	138	14	Yes	0.3
Full Participation (FP)	Full	100%	Default	188	20	Yes	0.3
Business As Usual without Energy Efficiency (BAU_WOEE)	Fractional	0%	Optional	38	4	No	0.3
Business-As-Usual with Increased VER & EV Penetration (BAU_INCR_VER_EV)	Fractional	0%	Optional	38	4	Yes	0.5

Figure 26 Scenario Table

## Model Results and Scenario Analyses

BAU is the baseline scenario for which the dataset is sourced from EIA dataset and FERC's "National Assessment of Demand Response Potential" reports. The first 10 years (2000-2009) have the same dataset across the scenarios – BAU, EBAU, and AP. For the subsequent 10 years (2010-2019), the data for BAU, EBAU, and AP scenarios are sourced from the FERC's "National Assessment of Demand Response Potential" report. The BAU\_WOEE dataset for baseline scenario without energy efficiency measures are same as BAU except that all demand reduction from energy efficiency measures are calibrated to zero. In the same light, the BAU\_INCR\_VER\_EV dataset for increased penetration of VER and EV are the same as BAU baseline scenario except that VER and EV increase is calibrated to 0.5%/year.

The following results illustrate the key dynamics that influence and determine the DR technology diffusion:

1. Increasing DR penetration does not necessarily translate to profitability:

Even though the DR penetration is higher in the AP and EBAU scenario when compared to BAU, the cumulative profits is larger in the BAU scenario. A closer look at the revenues and costs for all three scenarios reveal that the costs increases more for the same level of revenue

increase across AP and EBAU scenarios than in BAU scenario. This can be explained by the effect of number of DR players on the LMP fraction that is paid to enrolled customers. As the competition increases, the DR market becomes a buyers market and as a result the LMP fraction demanded by the customers increase resulting in increased costs for the CSP. Also, it leads us to a critical insight that the profitability of CSPs is highly sensitive to the LMP fraction that is paid to customers. There are also policy implications that arise out of this finding. The new FERC 745 ruling would no longer compensate the CSPs based on the aggregated curtailment rather it would be based on individual reductions below the Peak Load Contribution for each of its enrolled customers. This has the effect of nulling any advantage from demand aggregation and economies of scale leaving little incentive for CSPs to aggressively recruit consumers with lower capacity to offer for curtailment.

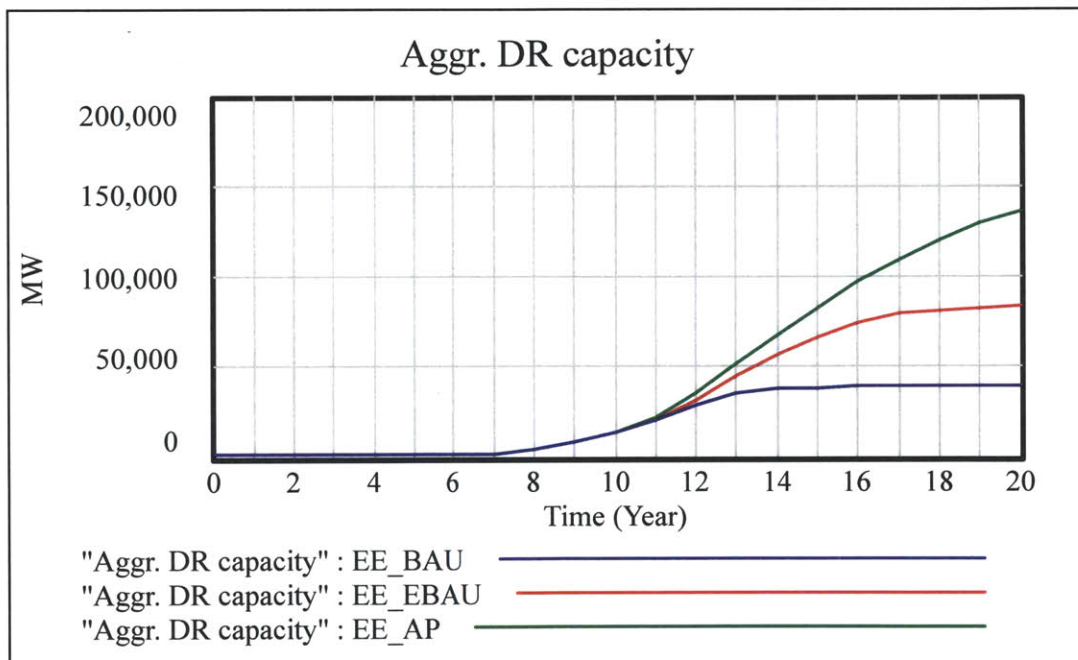


Figure 27 Aggregate DR capacity across scenarios BAU, EBAU, AP

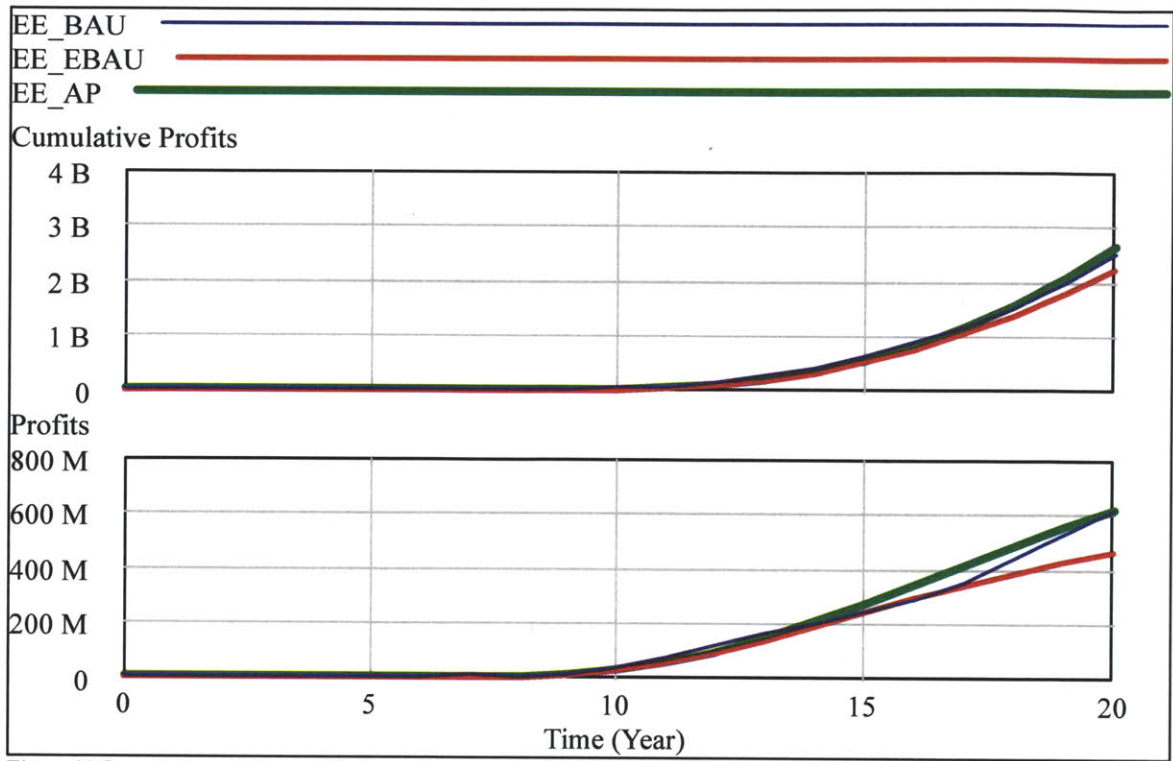


Figure 28 Cumulative and Annual Profits across scenarios BAU, EBAU, AP



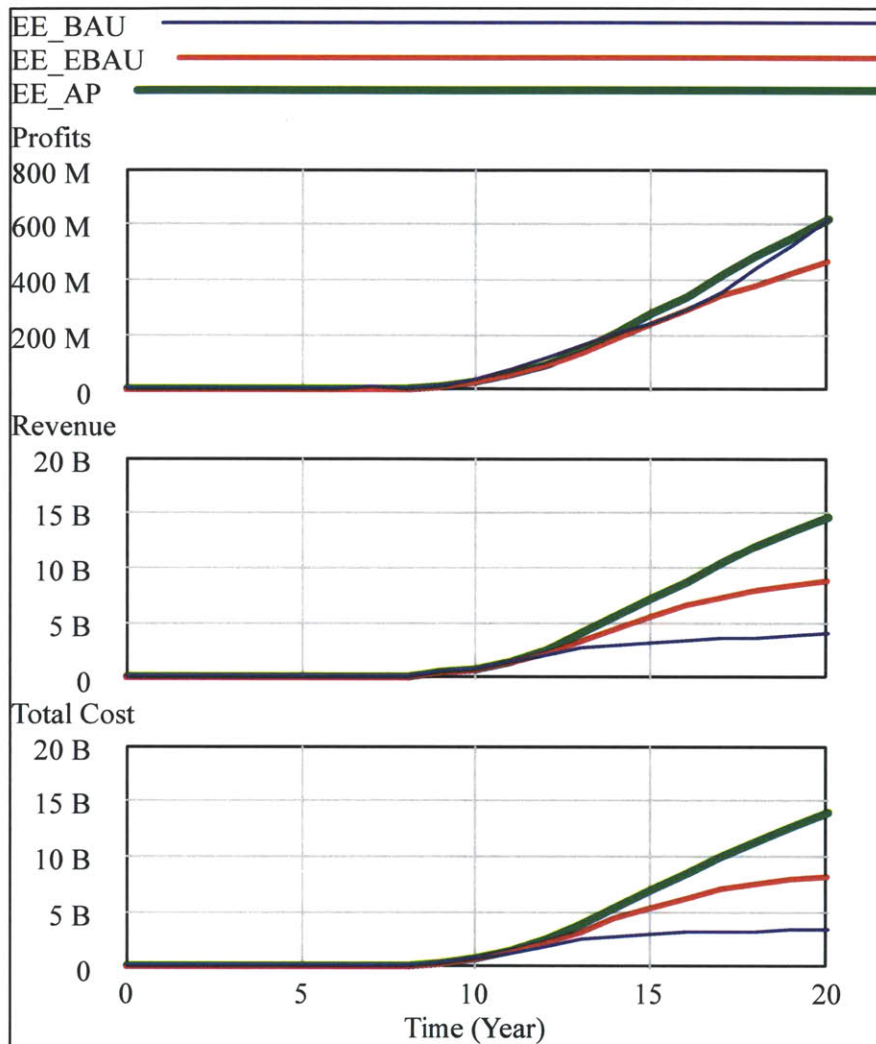


Figure 29 Increasing Costs with increasing Revenues in EBAU and AP scenarios

2. Price and Performance emerges as the most important adoption factor:

Willingness to adopt DR based on Performance and Price emerges as the key influencing dynamic for adoption of DR more than other factors combined. As can be noticed in the following results, the adoption curve is influenced both in shape and magnitude by the price and performance factor. The price component is more dominant and is dictated by the LMP, while the performance factor depends on the product development budget, productivity and the advancement of technological infrastructure such as AMI. Advanced level of automation

such as “Set and Forget”<sup>7</sup> provides the consumer with freedom to program the settings in an user friendly and non-intrusive way while it also improves the perception of performance in the consumer’s mind.

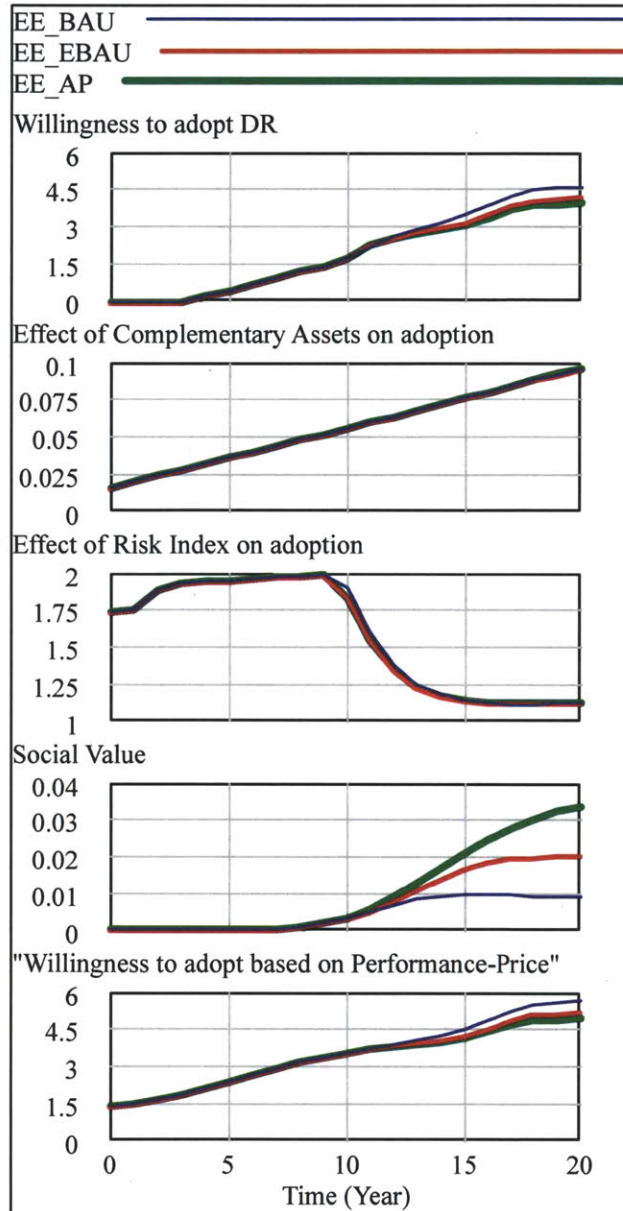


Figure 30 Electricity Prices and financial incentives emerge as the dominant drivers of DR adoption

<sup>7</sup> “set it and forget it” phrase used to describe easy-to-use and high level of automation in <http://eetd.lbl.gov/EA/emp/reports/lbnl-5063e.pdf>



3. DR fatigue has limited impact on DR diffusion:

Although DR adoption decreases with increasing DR overhead, also called, “DR Fatigue”, it is noticed that the influence of DR fatigue is limited when compared to the effect of average electricity price. For instance, increasing the DR overhead by 100% resulted in no significant change in DR capacity.

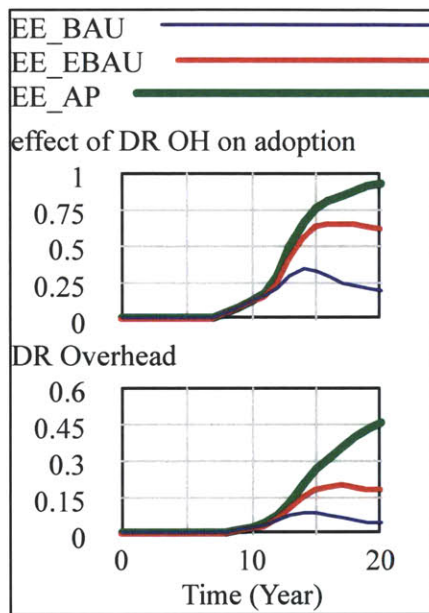


Figure 31 Effect of DR fatigue across BAU, EBAU, AP scenarios

4. Net benefit from DR adoption is extensive:

The short-term Supply-Demand Shortfall increases as DR penetration increases and as DR is increasingly perceived as a reliable resource. Paradoxically, the capacity utilization factor reduces with increasing levels of supply-demand shortfall. This paradox is explained by increasing levels of DR capacity. DR fills in the supply-demand shortfall by acting like a virtual power plant. Although it would in the long run affect the profitability of generators, the impact is insignificant compared to the cost savings to the utilities arising from avoided transmission and distribution systems upgrade. In addition, there are cost savings to be reaped from reduced power plant operational capacity and avoided investment costs in building new capacity. These results serve as encouraging signs for the risk-averse regulators and utilities in

the regulated market to embrace DR technology and facilitate a wholesale market structure that allows CSP to trade DR as a capacity resource.

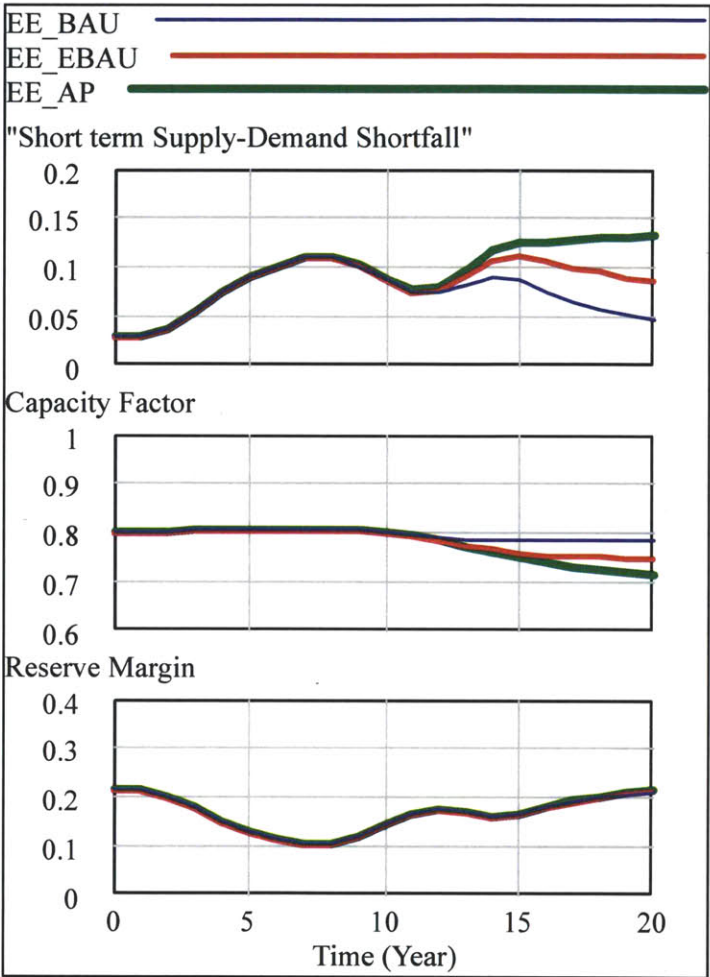


Figure 32 DR as a reliable resource - Decreasing capacity utilization despite increasing supply-demand shortfall

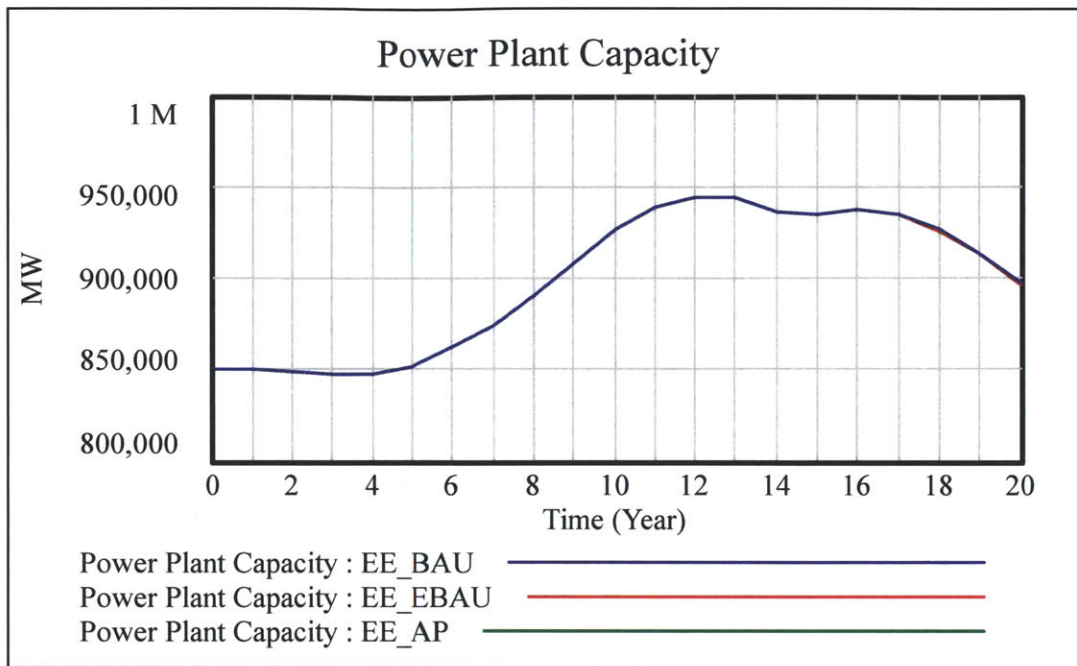


Figure 33 DR serves to reduce the total power plant capacity requirement

5. Energy Efficiency solutions are competing as well as complementary to DR:

Energy efficiency serves to reduce the energy usage and its effects are verified by looking at the magnitude of reduction in short term supply-demand by using energy efficiency solutions. This finding may at first seem one to conclude that energy efficiency measures competes with Demand Response technology, i.e. if energy efficiency were to increase the amount of capacity available for DR reduces. However, the dynamics in a complex market are never so simple. The level of DR overhead actually reduces with increasing levels of energy efficiency measures. This serves to increase the willingness to adopt DR. Also, the DR capacity in both scenarios remains the same, thus DR and EE are complementary as well as competing technologies.

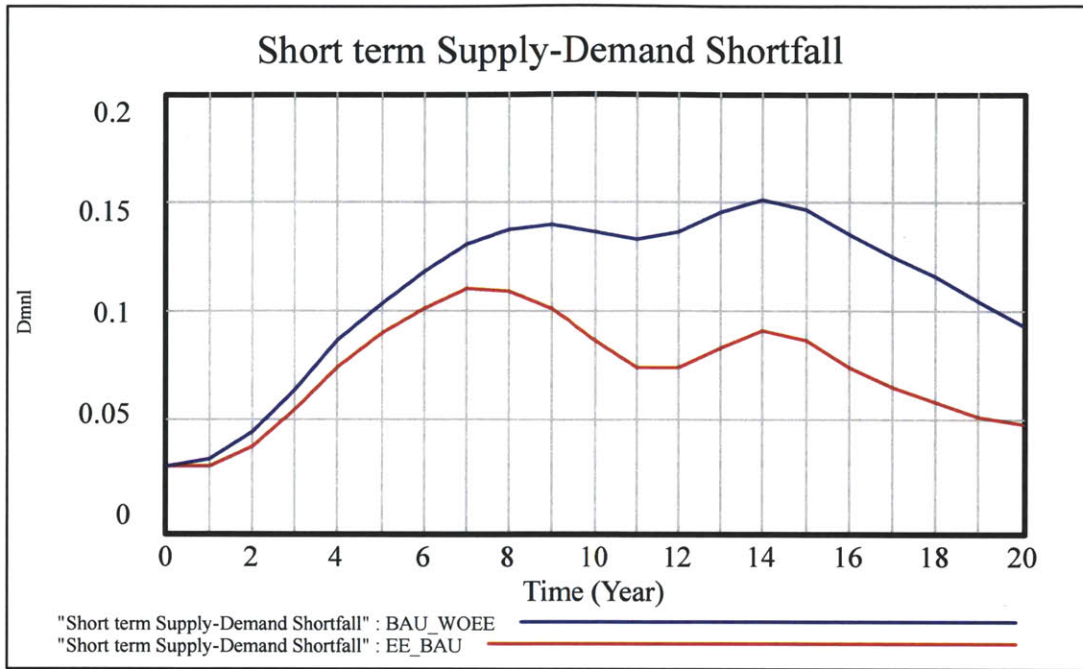


Figure 34 Effect of energy efficiency on short term supply-demand shortfall

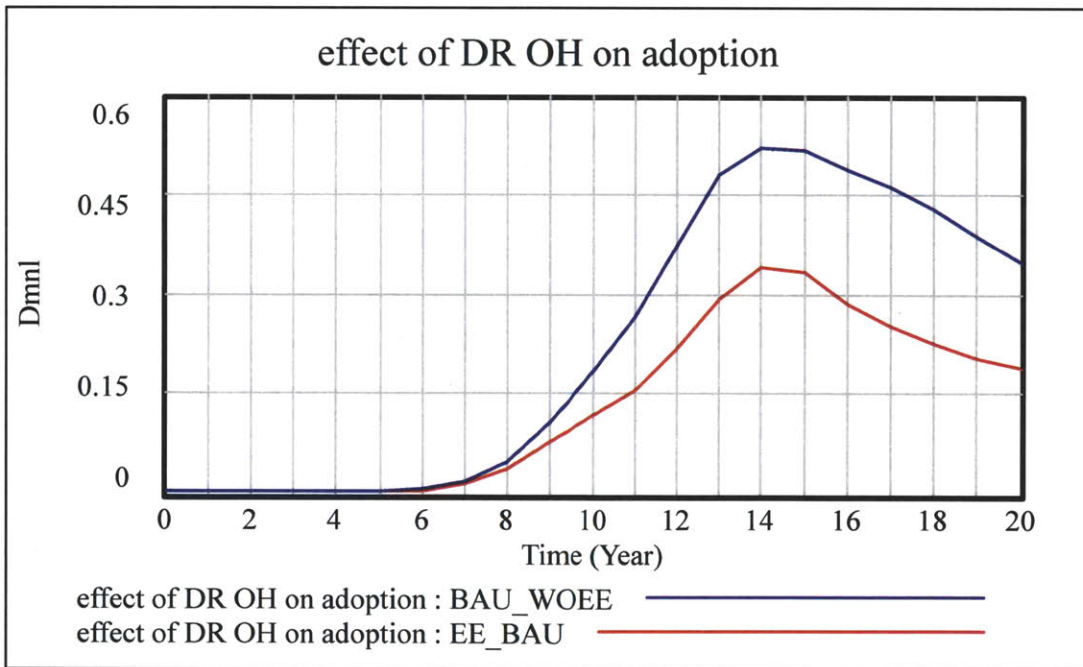


Figure 35 Effect of energy efficiency on effect of DR overhead variable

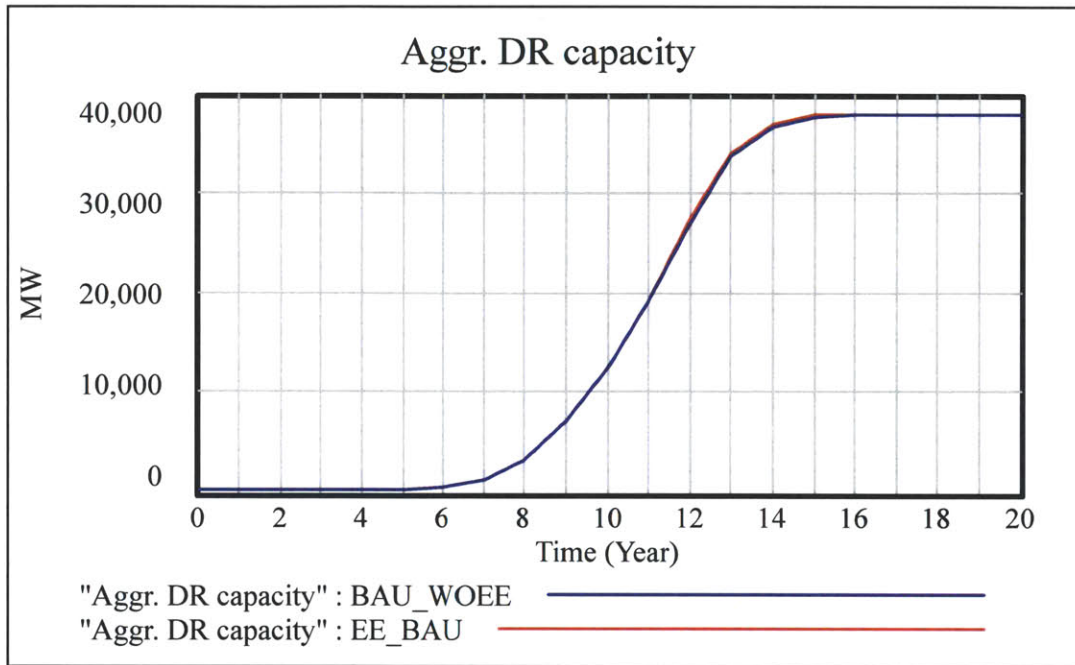


Figure 36 Effect of energy efficiency on Aggr. DR Capacity

6. Energy Efficiency measures reduces investments in new power plant capacity just like DR:

Energy efficiency serves to reduce the capacity additions by 33% by the year 2019. Energy efficiency measures have the added impact of permanently changing the behavior of consumers to energy without additional investments.

Both Energy efficiency and demand response reduce the short-term supply-demand shortfall and have the effect of delaying investments in power plants. One implication that emerges is that, it provides policy makers and investors flexibility to delay an irreversible investment into the future. This provides them more options and a 'value from waiting'. It becomes particularly more important in the context of new renewable energy technologies (RET), as these are often modular and exhibit steep learning curves. However, both these factors have counteracting influences on the value from waiting. A modular technology is quicker and easier to build and hence delaying RET deployment decreases the return on investment, whereas steep learning curve of RETs increase their performance to cost ratio over relatively short time, thus delaying RET deployment increases the returns. Thus, energy efficiency and

demand response influence even the complementary assets such as variable energy resource adoption and electric vehicles diffusion.

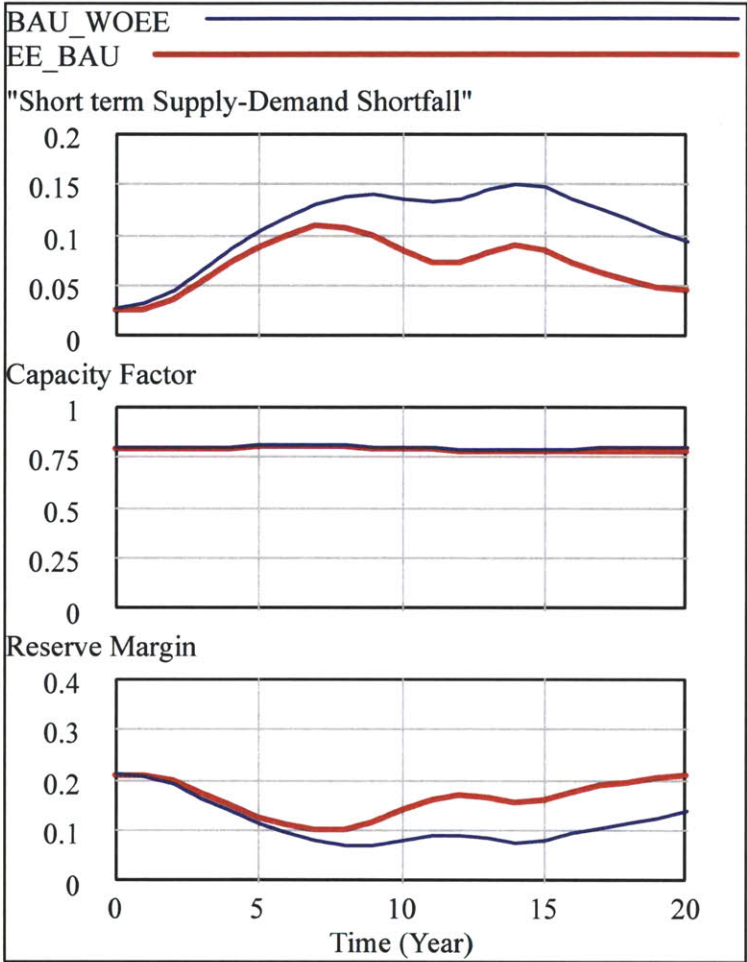


Figure 37 Effect of Energy Efficiency plot 1



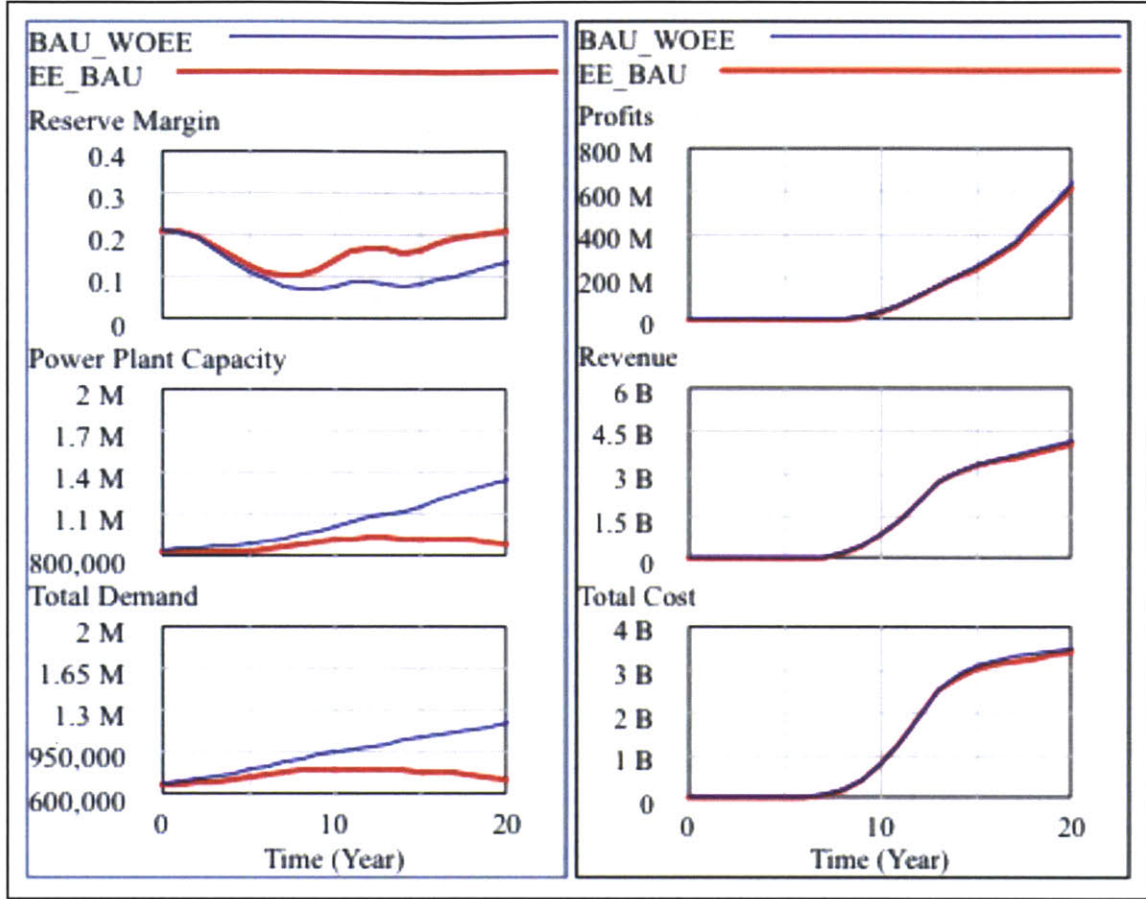


Figure 38 Effect of Energy Efficiency plot 2

7. Policy measures increasing VER and EV penetration aid DR adoption, but marginally:

Climate change policies that encourage increased integration of renewable energy technologies into the grid and usage of electric vehicles aid DR adoption. However, the impact is marginal. In the baseline scenario (BAU), the change in VER and EV penetration rate per year was set to 0.3 and 0.1% respectively. In the increased VER and EV adoption scenario the change in VER and EV penetration were revised to 0.5% per year. The increased VER and EV penetration results in increased willingness to adopt DR and a surge in LMP due to increased demand from EV penetration and higher volatility from increased VER integration. However, the willingness to adopt DR is more dependent on price and performance of DR than the

influence that arises from complementary assets. Hence, the resulting increase in DR adoption is only marginal.

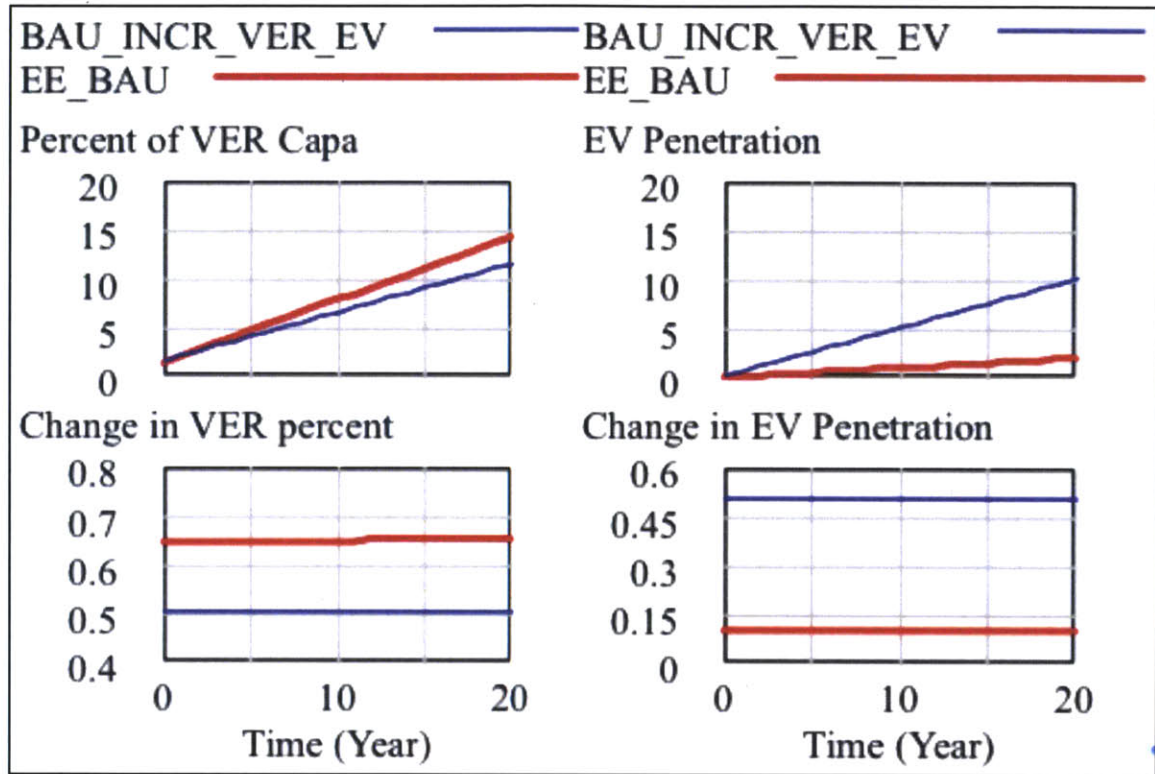


Figure 39 Impact of RET policy Plot 1



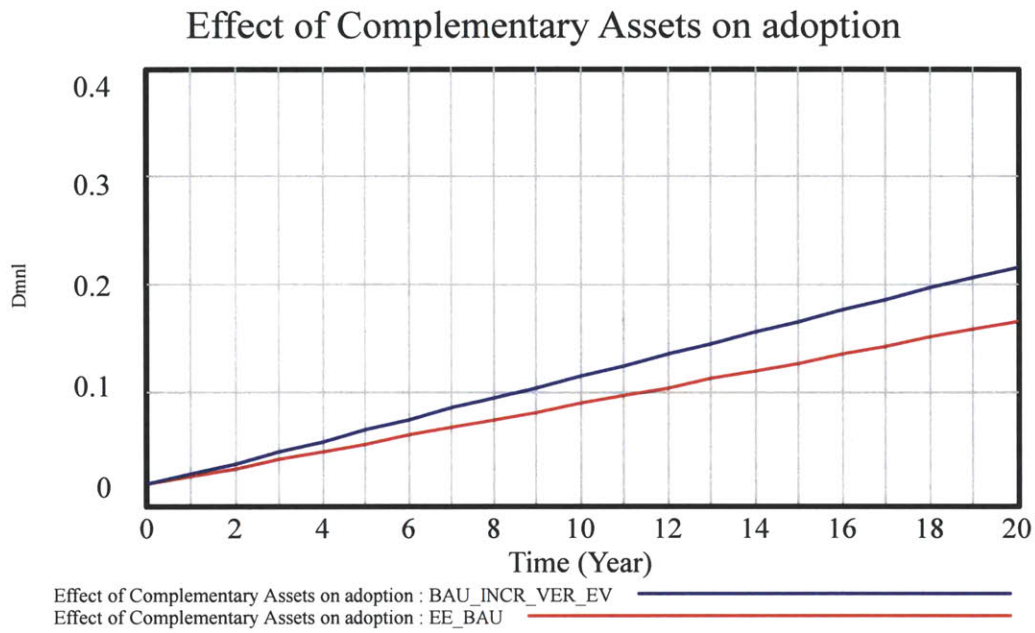


Figure 40 Impact of RET policy on variable “effect of complementary assets”

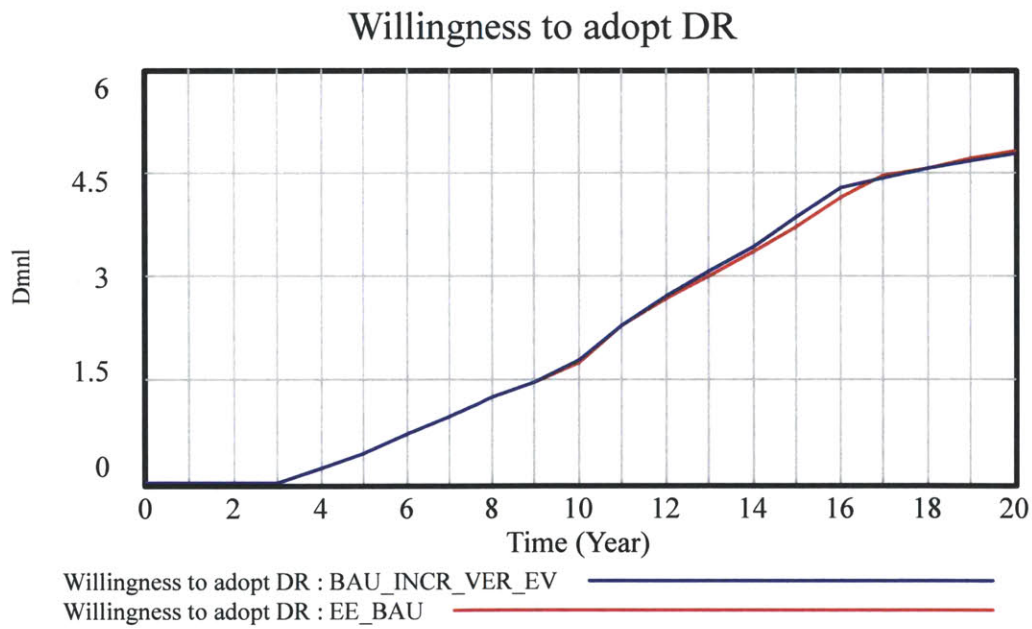


Figure 41 Impact of RET policy on variable “willingness to adopt DR”

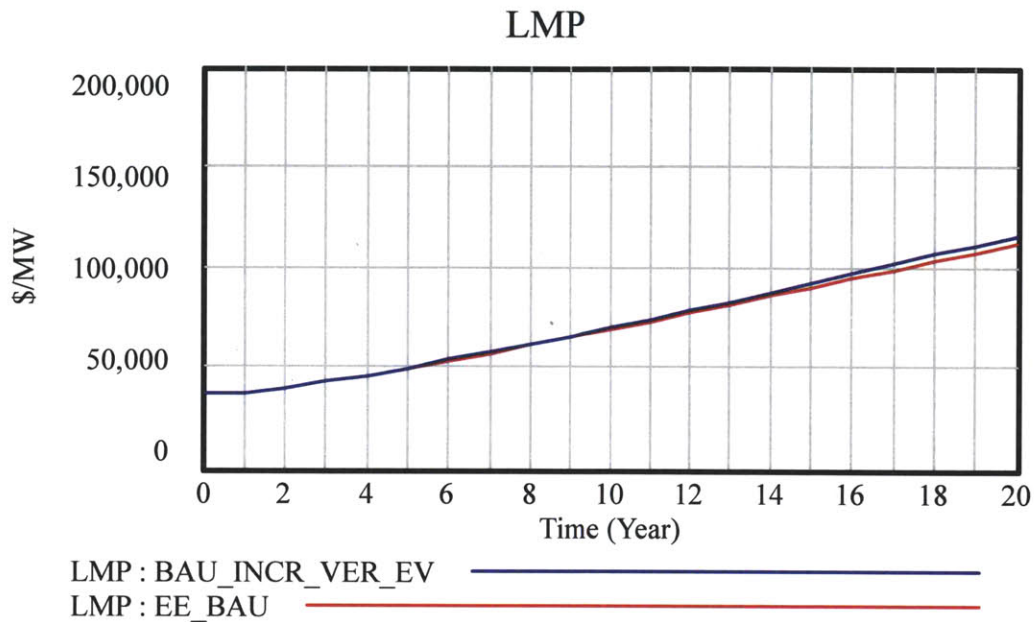


Figure 42 Impact of RET policy on LMP

The crucial parameters that arise from the System Dynamics model are the LMP, the aggregate DR capacity, and Profits. Apart from these, the impact from changing policy landscape and competition from Energy Efficiency measures should be continuously evaluated.

There are other compound scenarios that can be tested such as the effect of policy inclined towards reducing GHG emissions along with rapid inflation in energy prices. The policy parameters could be modeled as described in scenario 7 above along with carbon tax and cap and trade system which caps the amount of fossil fuels in the Capacity stock. The rapid inflation in energy prices could be incorporated directly in the LMP. This scenario for instance would not only increase the aggregate and potential DR capacity but also lead to increased rate of DR adoption.

Scenarios should not be in static light, in fact scenarios change and new ones take their place and the probabilities of them happening change too and thus, these scenarios must be revised as and when the changes in the system unfold.

## Chapter 7 – Implications on Strategy for CSPs

A crucial discovery that emerged from the scenario comparisons was the declining marginal profits for marginal increase in DR capacity and revenue. Such a finding has consequences on growth potential for CSPs. In this chapter, the implications of important dynamics that surfaced from scenario analyses would be considered and recommendations proposed to surmount those challenges.

It is first important to understand the customer segment and market potential before we deliberate on the growth challenges. The customer segments for DR can be largely classified into industrial, commercial and residential markets. The wholesale market participants along with commercial and industrial customers together represent the bulk of the total peak reductions in the US. Commercial and industrial customers, though fewer in number than residential customers, provide a higher proportion of load reduction potential than residential customers. Commercial and industrial customers are also more likely to have systems and technology in place to facilitate demand response program participation. In addition, many demand response programs are available only to customers above a certain capacity threshold(Federal Energy Regulatory Commission, 2011a).

### **Market Potential**

FERC's report on demand response potential, estimates that under highest level of demand response penetration scenario there would be a leveling of demand between 2009 and 2019. The reduction in peak demand from demand response is estimated to be between 38GW and 188GW by 2019. To provide some perspective, a typical peaking power plant is about 75 megawatts, so this reduction would be equivalent to the output of about 200 such power plants(Federal Energy Regulatory Commission, 2009a).

The figure below illustrates the different customer segments and the potential of DR in the year 2019 under different participation scenarios. Although small commercial consumers constitute a

minor fraction of the market, they are the metaphorical equivalent of “crossing the chasm” in the sense that unless the right business model and strategy is used to enroll the small commercial consumers, enrolling the residential consumers will remain a fantasy.

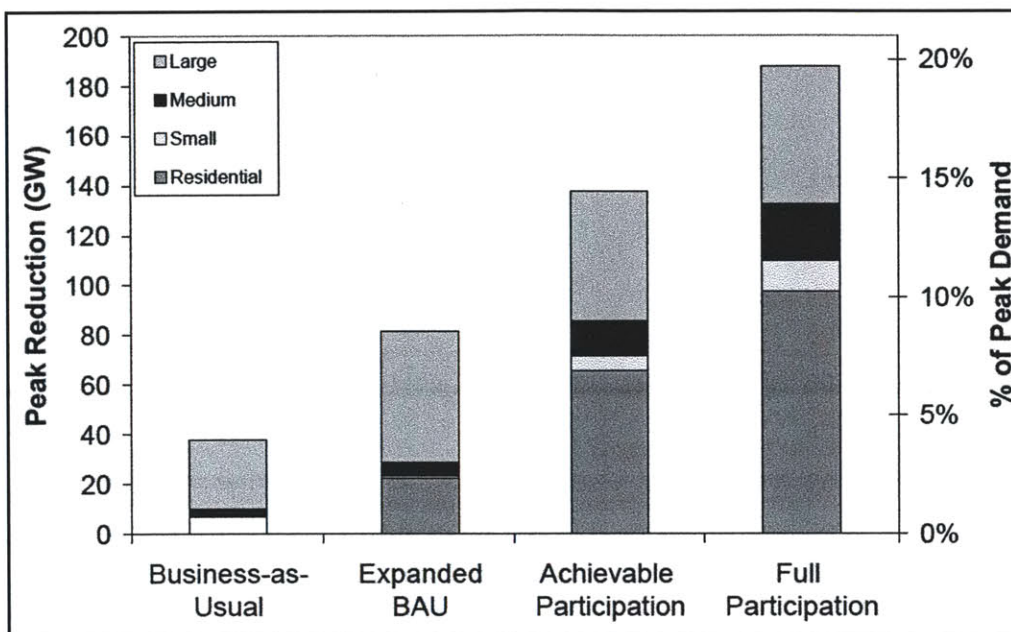


Figure 43 US DR Potential by Class in 2019<sup>8</sup>

### The Growth Challenge and dynamics facing the industry

The Curtailment Service Providers have so far focused on enrolling large and medium sized customers with individual capacity contribution of over 200KW into their DR programs. This customer segmentation strategy has worked well so far for CSPs as it has provided them with large aggregate capacity to bid for in the wholesale capacity market at a fraction of sales and marketing costs. The acquisition cost per MW of capacity has been minimal (see Table below). However, the large industrial and commercial customers constitute only a small percentage of the electricity customers. As more numbers of these easy to acquire customers enroll into DR programs, the DR market fast approaches saturation.

In the face of stagnating growth prospects, CSPs may be forced to look for growth opportunities in the international market or increase their share in the domestic market by enrolling newer smaller

<sup>8</sup> (Federal Energy Regulatory Commission, 2009a)

commercial customers. The international market, although lucrative, is mired with regulatory bottlenecks of its own. On the other hand, the smaller commercial consumers with individual capacities in the range of 20KW-200KW are segmented and geographically scattered, thus increasing the cost of acquiring these customers. CSPs will soon face the dichotomy of increasing their topline at the cost of eroding margins.

**Table 1 Profitability-Cost matrix for different customer classes**

Profit Margin	Cost to serve		
		Lo	Hi
	Hi	<u>CASH COW</u> : -Large commercials & Industrials (>200KW)	NA
	Lo	<u>DEVELOP</u> : Small Commercials – Grocers, Malls, Schools, Shopping Complex (20-200KW)	<u>AVOID</u> : Do not enroll right now –Residential (< 20KW)

The table above illustrates the problem in a nutshell. One segment to clearly avoid right now is the residential market, where the capacity on offer for curtailment is much lower than 20KW making the ROI unattractive. With the cash cow segment saturating, the CSPs must now develop the small commercials market; but to keep their margins from shrinking, CSPs need to challenge the existing cost and organization structure and evolve an effective plan to capture this fragmented customer segment.

### **Analysis of DMU & DMP for small commercial consumer accounts**

Small commercial consumers are dispersed geographically across a wide array of sectors such as education, hotels, restaurants, bakeries, groceries, gas stations and shopping malls. As a result, there is no common authority in charge of decision-making across these sectors; instead the role of DMU (Decision Making Unit) varies from industry to industry. The figure below illustrates the entities involved in the decision making process across different sectors.



The key decision maker for a family owned business such as a restaurant, bakery or a coffee shop is usually the owner who also partakes in the decision making process from need recognition to final commitment.

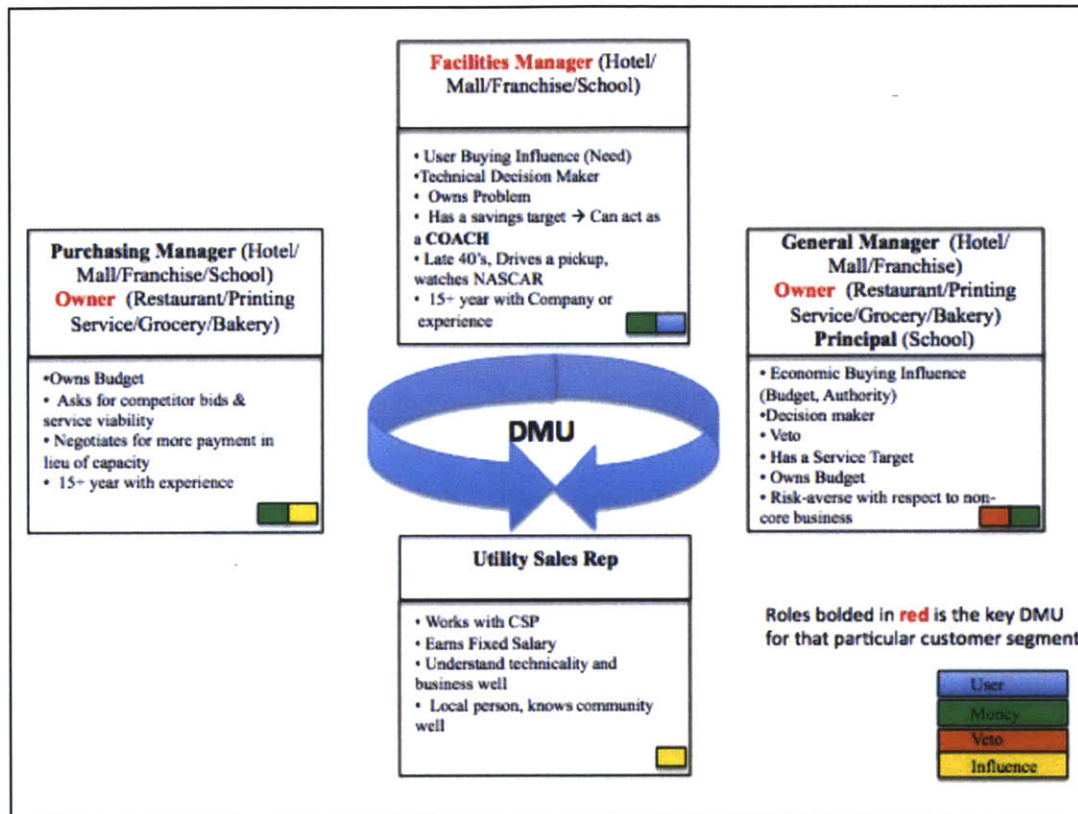


Figure 44 Decision Making Units for different Small Commercial Consumers

In contrast, the key DMU for a franchise or hotel or a mall varies at different stages of decision making. The initial point of contact is usually the Facilities Manager on whom the bulk of the marketing and sales awareness campaign is targeted through tradeshow, brochures and direct mail. The Purchasing Manager participates in the evaluation process and negotiates on the financial aspects of the contract. The final decision often lies with the General Manager who holds the economic buying influence and verifies that the proposition does not affect the service target of the organization. Where possible, it would be beneficial to partner with the local utility to leverage the local network of the utility sales personnel to identify and initiate first contact. The decision making process can be broken down to following stages:

Need Recognition and Problem awareness, Interest generation, Evaluation, Commitment and Contract renewal. The figure below illustrates the decision making unit and the decision making process for small commercial customers.

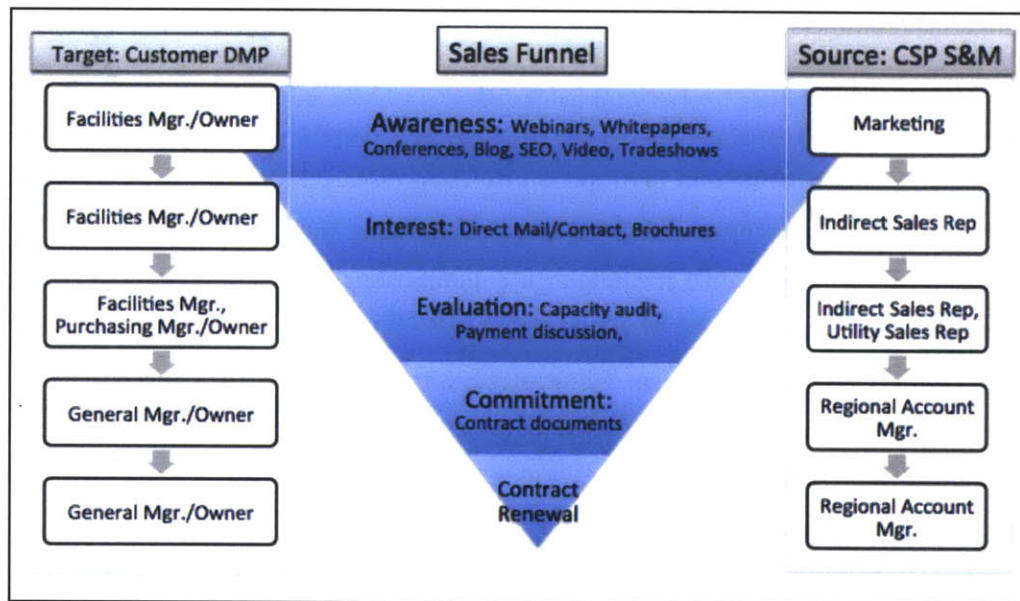


Figure 45 Decision Making Process and DMUs in small commercial consumer account acquisition process

## Understanding Barriers to Energy Demand Response

A critical element in devising a strategy for the CSP sales organization is to first understand what is preventing these firms to expand into the residential and small commercial segment.

The United States Government Accountability Office (GAO) exposes that energy demand response programs face three main barriers to their introduction and expansion (US Government Accountability Office, 2004):

- *Regulations that shield customers from short-term price fluctuations:* GAO exposes that the costs of supplying electricity are generally not reflected in the prices that residential consumers see in the retail markets where they buy electricity and that these prices are generally a single average price prescribed by regulation for all purchases made over an extended period. Since there is no variation seen in retail prices, customers lack the information and the incentive to respond to the actual variation in supply conditions throughout the day and from season to season. (US Government Accountability Office, 2004)

- *Absence of needed equipment installed at customers' sites:* In terms of infrastructure for customers, GAO finds that although the needed technologies are commercially available, most residential customers lack the necessary equipment (meters, communication devices, and special tools) to participate in demand response programs. These devices are not installed in most customers' homes and businesses(US Government Accountability Office, 2004).
- *Customers' limited awareness of programs and their potential benefits:* In areas where energy demand response programs are available, some customers are unaware or of them or confused about how they could benefit from participation. In most cases, customers do not recognize their own sources of electricity consumption (demand) ignoring options to significantly reduce their demand without significantly affecting their commercial operations or household comfort.(US Government Accountability Office, 2004)

Chao in his article "Demand Response in Wholesales Electricity Markets: The Choice of Customer Baseline", presents the two leading institutional barriers that prevent the full realization of energy demand response in residential markets are:

- *Lack of advanced metering infrastructure:* In addition to GAO's argument presented above, Chao evidences that only the size of some large industrial and commercial customers can justify the expense of advanced metering infrastructure, communications, and enabling technologies at this time(Chao, 2010). The industry is unable justify the costs of installation for individual household owners.
- *Widespread practice of fixed uniform Retail Rates:* Firstly, Chao finds in his article that customers that consume most of their energy during low-cost, off-peak periods are charged the same price as those who consume most of their energy during high-cost, peak periods. Secondly, fixed rates have disincentives to promote price-responsive demand, because it could lead to retail competition and reduce profit margin(Chao, 2010).

In this section, we focus on the role of sales and marketing organization in CSPs in helping overcome the limited awareness of small commercial customers to energy demand response programs and benefits from enrolling in these programs.

### **Current CSP Sales Organization Structure**

CSPs will increasingly finding it expensive to recruit new customers through their existing sales and marketing organization structure. These firms currently employ a direct sales force not significantly



different from a traditional B2B sales force organization. The current sales organization employs people with “farmer” skills, who establish and maintain long-term relationships with customers while cultivating a solid network with them to find new leads. The figure below symbolizes the structure of traditional sales organizations and its interaction with the marketing organization. The organization is composed of sales representatives with farmer skills all reporting to a key account manager. Account managers directly report to the National account managers responsible for the overall sales for the Commercial and Industrial customers, and they in turn report to the VP of sales. On the marketing side, the VP of Marketing leads both the Commercial and Industry marketing managers. These managers are responsible for providing the information, data and resources needed by the Commercial and Industrial National Account Managers in the sales organization.

Another function implicit in this structure is the type of control exerted on the sales organization. From our experience in this industry and interviews with practitioners in the field, we discover that the CSPs extend a behavior-based control over them. This is, in some sense, a paternalistic approach whereby managers dictate to sales force what they believe is the "correct" approach in achieving the firm's goals(Oliver & Anderson, 1994). This type of control allows these firms to establish long-term relationship with customers, thus securing contract renewal and cross-selling energy efficiency solutions to industrial and large commercial customers. Also it enables the firm to deliver a consistent product and service message and receive unfiltered feedback that enhances innovation in value delivery; and ensure product or service and company loyalty.

In a behavior based sales organization, a salesperson’s earning should be tightly related to direct sales force salary perceptions (e.g. 80% fixed and 20% commission) as such a scheme encourages salespeople to accept as legitimate the authority of management(Oliver & Anderson, 1994). Management reviews in such an organization structure are usually based on a combination of objective and subjective metrics. It measures what salespeople can do (their knowledge, skills, competencies, and aptitudes) and it measures what salespeople are (their appearance, hygiene, education, age)(Anderson & Onyemah, 2006).

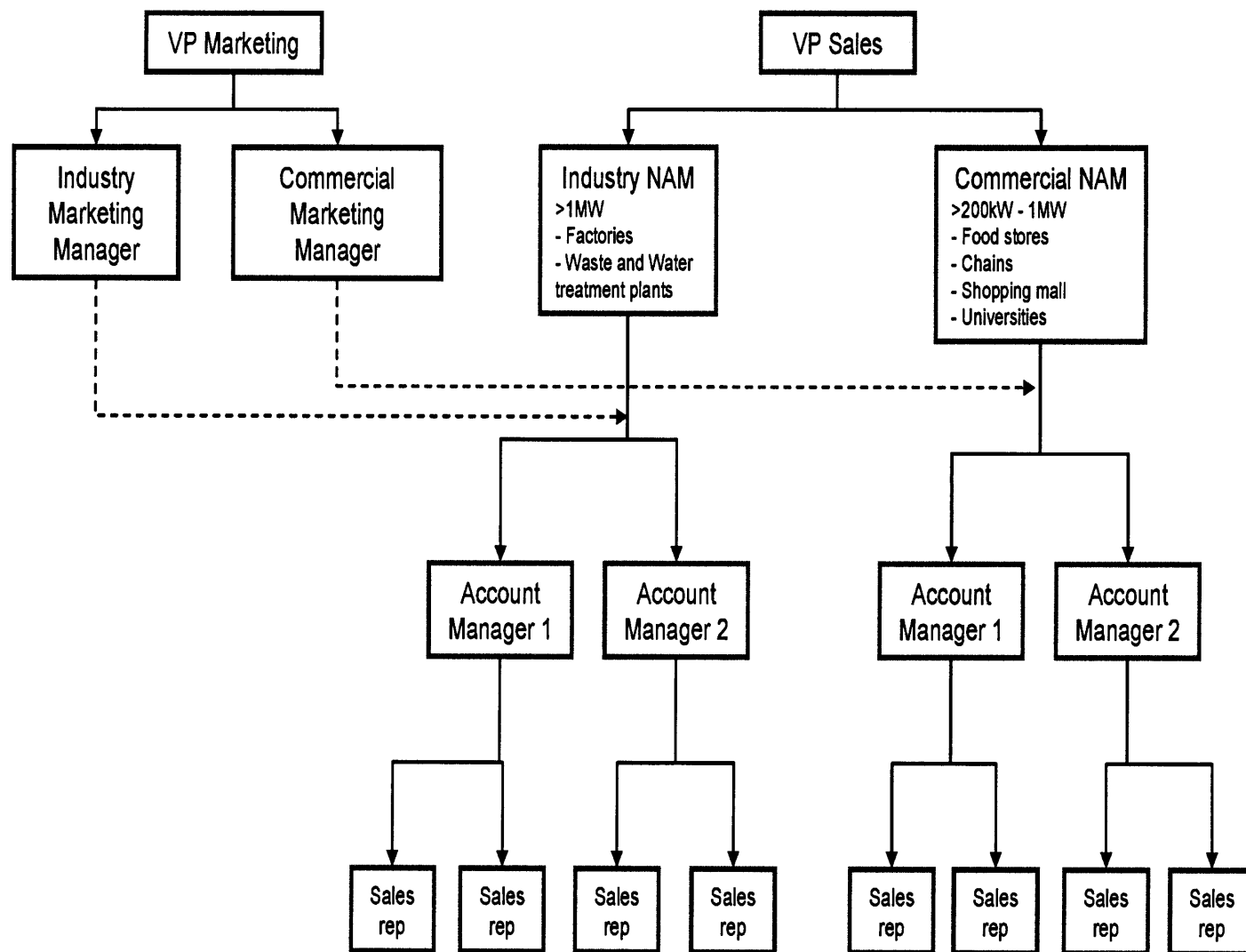


Figure 46 Current Sales Organization of CSPs

There are several advantages and disadvantages of the traditional direct sales force structure employed by CSPs. They are listed across the following dimensions:

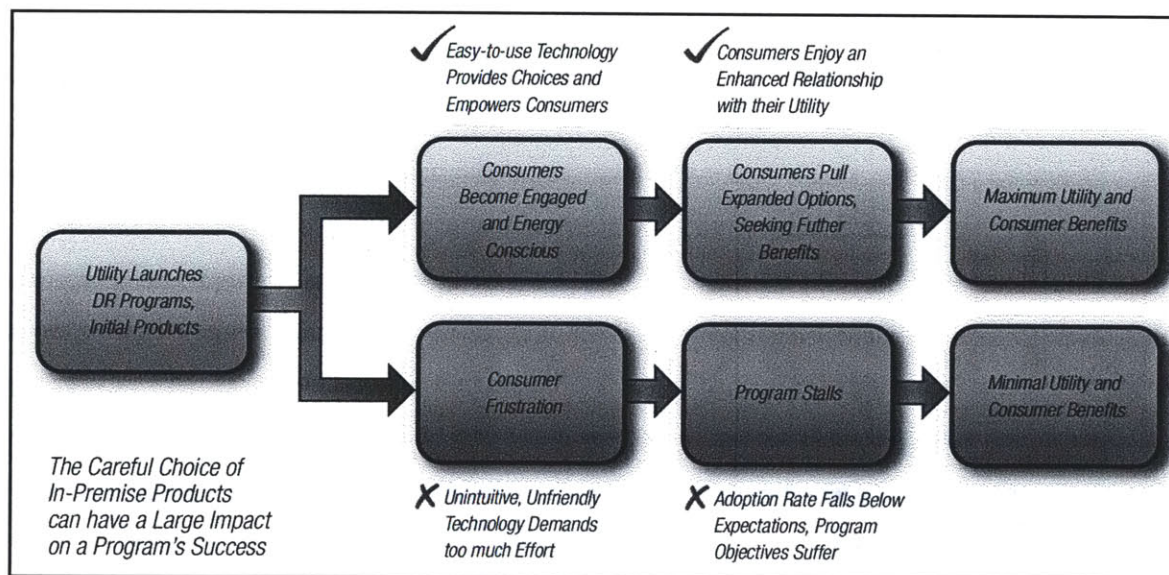
1. **Control:** The direct sales force structure enables CSPs to maintain and increase control over how the sales force interacts with the customers. In general, a direct sales force helps enforce confidentiality of the client list, delivers a consistent product and service message and receives unfiltered feedback that enhances innovation in value delivery, ensures sales personnel, product and company loyalty, and finally, it enables setting and monitoring sales targets for individual sales personnel(Steenburgh, 2006).
2. **Coverage:** The current sales organization structure adopted by these firms has proven to be effective in building long-term relations with existing industrial and commercial customers but has major shortcomings in attracting new ones. In part, this disadvantage is due to the restricted coverage of their direct sales force. Sales personnel with “Farmer skills” have the ability to cultivate relations but usually fail to seek further due to limited skill sets, and regional coverage limits(Steenburgh, 2006).
3. **Cost:** This is probably the biggest shortcoming that prevents CSPs from enrolling small commercial customers. The return on money invested in selling Energy Demand Response products and services to commercial, industrial and residential customers is marginal. Profits in this industry are achieved through aggregating large volume sales in terms of dollars/kW saved. Individual residential customers alone cannot be part of the profitable business equation since the realized capacity payments are significantly lower than large commercial or industrial customers. A direct-sales force structure does not have the proper incentives, coverage or cost structures to explore the small commercial market space.

### **Proposed Sales Organization Structure**

The solution proposed in this section is oriented towards modifying the sales and marketing organization structure to address the concerns related to customer awareness and effectiveness of message transmission between the CSPs and the potential residential and small commercial customers.

The figure below illustrates the dynamics involved in the firm/utility/customer relationship towards a successful implementation of energy demand response program. This figure highlights the importance of offering products and services that are "easy-to-use" in the first place, to provide choices and empower consumers to buy them. However, the real challenge is designing a marketing and sales organization capable of transmitting the right message to residential and small commercial customers.

These dynamics reveal that CSPs have to first, work towards developing a high performance, easy-to-use products and services. Over the last few years, CSPs have invested in smart systems and technologies and developed products and services that address the need in the market place. The second step is to effectively communicate to their customers how these products and services can reduce their expenses by optimizing their energy consumption. To achieve these benefits and increase the success rate, the design of programs should consider appropriate outreach, the introduction of necessary equipment, and the ease with which customers can participate (GAO, 2004). If either fails, adoption rates will fall below expectations and program objectives will not be met.



**Figure 47** Utilities are taking the lead to empower homeowners to change<sup>9</sup>

<sup>9</sup> Niraj Bhargava. "Empowering Consumers to Manage Energy". Utility Automation and Energy. September 2008.

In order to address the challenges of the market and the dynamics presented in the figure above, the solution visualized to reach residential and small commercial customers is conceptualized in Figure: Proposed Sales Organization Structure.

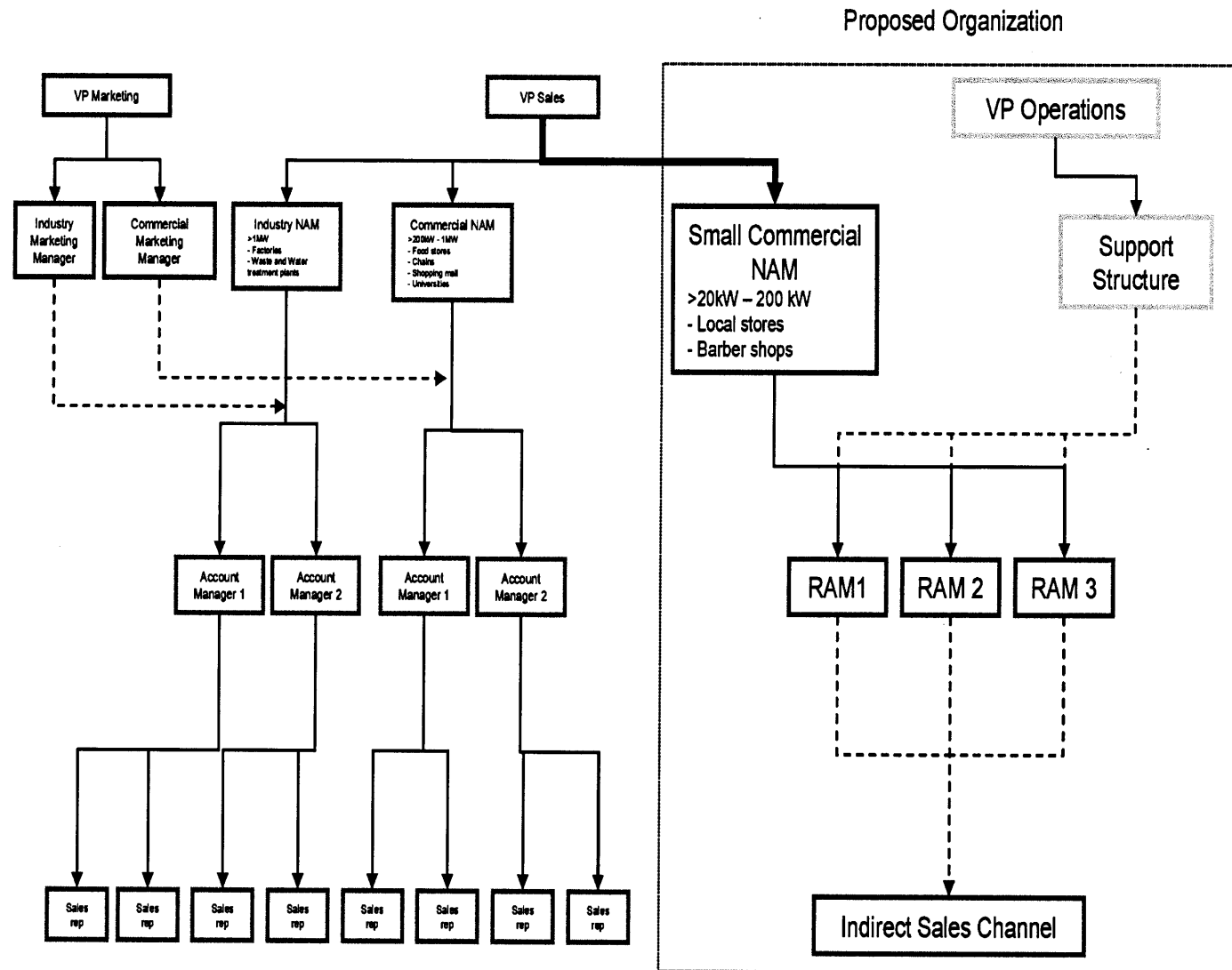
We propose creation of a hybrid sales organization structure capable of delivering a consistent message to industrial, large, small commercial and residential customers. For large commercial and Industrial customers we propose to maintain a direct sales force incentivized through a behavioral-based culture, similar to the existing sales organization structure. Whereas for small commercial customers we propose an indirect sales channel with “hunter” skills incentivized appropriately to enroll new customers; in other words, controlled under an outcome –based culture.

In this new organization structure, the indirect sales force are employed to target small commercial and residential customers would directly report to the Regional Account Managers under an outcome-base system. Each Regional Account Manager would report directly to a new Small Commercial National account Manager within the sales Organization and would maintain a close constant with the Operations team (service, maintenance and product development) to enhance continuous product development, implementation and service feedback. We believe this enhances the value delivery process. Although independency and self-regulation will be allowed (for the indirect sales channel), control will be enhanced through targets and objectives explicitly established in short/mid/long term contracts.

Our rationale to hire an indirect sales force with hunter skills and evaluated through outcome based system is based on:

Firstly, small commercial and residential customers require clear and strong incentives to adopt energy demand response schemes. Sales personnel with skills such as persuasiveness, strong sense of urgency, and adept at bouncing back from rejection amongst others are needed to acquire these hard-to-convince customers. The sales force in charge of recruiting these types of customers should be constantly sourcing and qualifying new leads, continuously obtaining appointments, keen on delivering presentations that address customers concerns, and negotiating and securing new businesses (Steenburgh, 2006).

Figure 48 Proposed Sales Structure



Secondly, we believe that in order to properly incentivize the indirect sales force, an outcome-based control should be implemented. With outcome based control systems, CSPs can measure and reward results in terms of the enrolled capacity. We propose to establish a compensation system to closely tie two or three key metrics, and a substantial portion of each salesperson's income should be based on their performance.

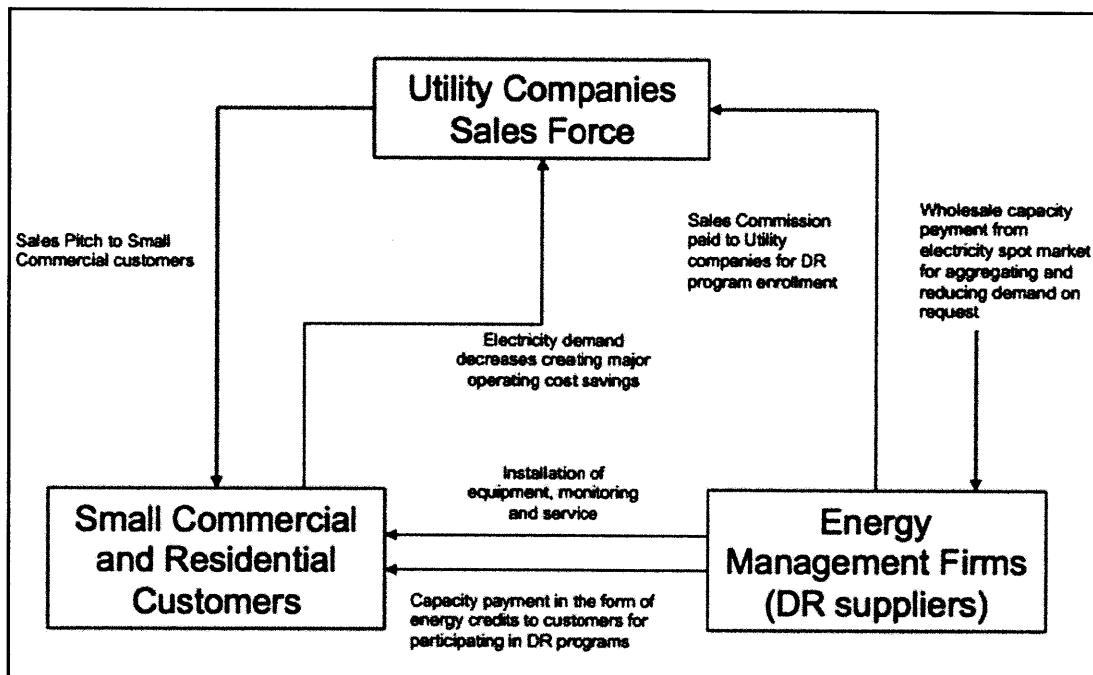
Finally, the methodology used to present the new proposed sales organization structure has risks and challenges that need to be monitored constantly. Questions on whether this proposed organization would work naturally arises; therefore, we analyzed the potential feasibility of the indirect sales structure using the following dimensions as a framework to arrive at an answer:

1. **Control:** This could be a major limitation to the proposed indirect sales force organization. With an indirect sales force, CSPs could endanger the effective delivery of a consistent message to the new small commercial customers. Also, the firms would not be able to fully control the services presented to the customers. In order to avoid these potential issues, a fine tuned outcome-based control system should be implemented. The main challenges in terms of control imposed by this structure (methodology) are as follows:
  - a. Time to train and learn is seen by the indirect sales force as time out of the field with a high opportunity cost and not exactly considered as time to experiment with new products (Olivier and Anderson, 1994).
  - b. Aversion to management control. The new indirect sales force might strongly oppose to management control imposed by firms (Olivier and Anderson, 1994).
  - c. Attraction to risk-making decisions motivated with high levels of extrinsic rewards (Olivier and Anderson, 1994).
2. **Coverage:** As opposed to control, coverage presents a major attractiveness to the new proposed organization. With an indirect sales force with "hunter skills", CSPs can increase their coverage quickly and effectively. Multiple examples in analogue industries support this argument. Sales people with a high sense of urgency and persuasive skills will enable a stronger coverage.
3. **Cost:** It is clear that with the new organization structure, the CSPs must reevaluate and optimize their existing cost structures to maintain their existing profit margins. In the

following sections, we investigate the cost and financial structure to arrive at a quantitative answer.

The next big question is “*Who should play the role of the indirect sales force?*” In addition to the proposed sales and marketing organization structure, we evaluate a potential collaboration model with two different indirect sales force providers:

**1. Value Added Re-seller:** In this business model we recommend partnering with the Utilities that currently supply the electricity to small commercial and residential customers. The utility sales force would help CSPs reach the small commercial customers under the proposed scheme. The figure below portrays the potential collaboration model between the energy management firms and the Utility companies’ sales force.



**Figure 49** Collaboration model with Utility companies

Under this scheme, Utilities would use its sales force to sell DR programs to customer. Curtailment Service Providers would install the equipment, monitor and service the customers and would earn capacity payments by enrolling the aggregate capacity in the electricity spot market. The CSPs would pay a fixed commission per sale to the utility companies, and the customers would be paid for



energy savings (demand reduction). Utilities are rightly incentivized in this proposed structure as in addition to earning commission from the sale, they also have the additional benefit of avoided investments in infrastructure costs such as generation, transmission and distribution upgrade due to demand reduction.

However, in this collaboration model the key concern that arises is whether the utility sales force possesses the hunter skills required to recruit new small commercial customers. Despite the natural synergies between the CSPs and the utility companies, we believe the lack of ‘hunting’ skills among the sales force voids any benefits that could arise out of this partnership.

**2. Construction contractors:** The construction contractors are a group of small and medium size companies dedicated to selling home improvement and construction services (and materials) to small commercial and residential customers. In addition, many of these contractors sell energy saving solutions to the same customer base. The extensive presence of these companies across the United States and their ability to sell home improvement services are more adequate for Demand Response programs, therefore we believe this collaboration model is more suitable to cover small commercial customers. Figure below describes the potential collaboration model between the energy management firms and the Construction contractors’ sales force.

Under this scheme, the local constructor contractors would use its sales force to sell DR programs to customer. Curtailment Service Providers would install the equipment, monitor and service the customers and would earn capacity payments by enrolling the aggregate capacity in the electricity spot market. The CSPs would pay a fixed commission per sale to the construction contractors, and the customers would be paid for energy savings (demand reduction). In addition to bringing in the right skills to increase coverage, the construction contractors have the potential to provide operational cost reduction using their existing maintenance workforce. They could go on to serve the role of a composite channel partners as the partnership develops. We believe this partnership model is ideally suited to serve the small commercial customers.

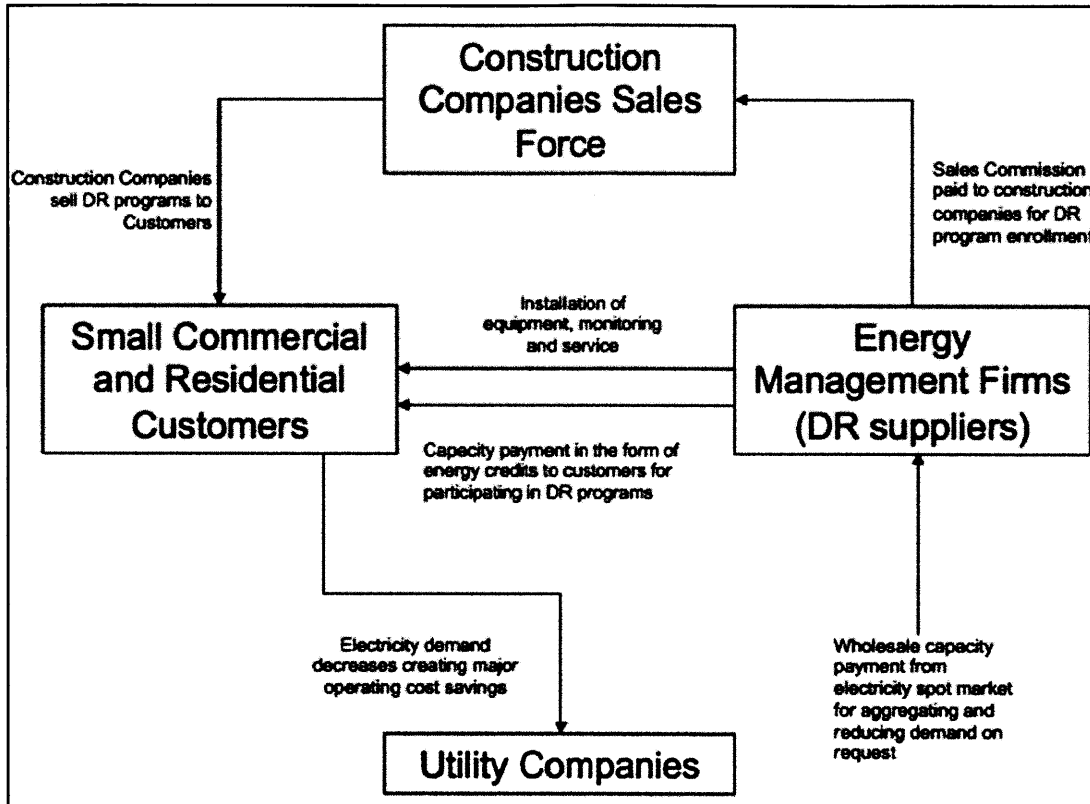


Figure 50 Collaboration model with Construction Companies

### Compensation Structure

The fundamental difference that arises in the new compensation plan is in the incentive structure of indirect sales force personnel who replace Business Development Associate (BDA) in the erstwhile sales organization structure. The indirect sales force personnel are part of the intermediary organization such as the construction contractor sales force as described earlier. The training, operational and marketing costs for the sales force would be directly borne by the CSP. However, the compensation would be purely commission based. The intermediary firm would be compensated at 20 to 30% of margin depending on their annual performance.

It is also important to align the personnel quotas and targets based on the revised compensation structure. The key metric that influences these is \$/MW figure, i.e. sales cost per MW of capacity enrolled as well as the revenue generated per MW of capacity.

Each account in the large commercial and industrial consumer base contributed anywhere between 200KW to 5MW capacity, whereas each individual account targeting the smaller commercial

segment is worth under 50KW on an average. Thus, the sales personnel need a more broader and effective coverage to make the sales target as before. For example, in the traditional segments a BDA needs to enroll on an average 100 sites of 300KW capacity to meet his or her target of 30MW/yr. To meet a similar target, the new sales force would need to enroll six times more accounts in a single year, which is humanely impossible. The targets for smaller accounts need to be revised to reflect the fragmented customer base and smaller capacities on offer. We arrive at a target of 10MW/yr for each personnel which amounts to approximately 200 sites/yr in order to balance the influence of two conflicting factors - the reduced time to close a sale for a smaller commercial as against the higher number of account enrollments needed due to the smaller capacity contribution of each client.

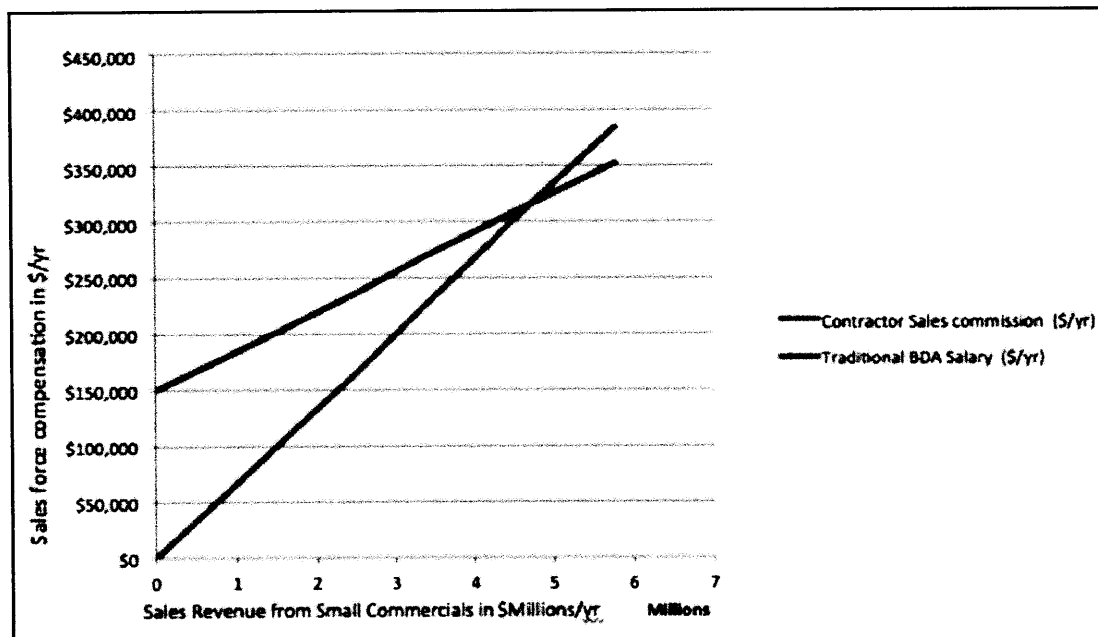


Figure 51 Traditional vs. Indirect Sales Force compensation structure as a function of sales

## Financial Structure

Based on the personnel cost structure (hypothetical data), the financial forecast is calculated. It is estimated that each region can contribute \$1.2 Million to the bottom line (after tax) yielding a national (net) profit target of \$10 Million (8 regional grids in the USA).

Financial Structure		Units
Payment to Customer	25.00%	
Avg. Capacity per customer	50	\$/KW
Avg. Capacity Price	\$110.00	\$/KW
Annual Payment	\$1,375.00	\$/yr
# sites	1000	sites
Total Annual Capacity (for 1 region)	50	MW/yr
<b>Revenue</b>	<b>4,125,000</b>	<b>\$/yr</b>
Sales Salary Costs (for 1 region)	1,726,250	\$/yr
Commission to utility	206,250	\$/yr
Incremental General OH	100,000	\$/yr
Training OH	300,000	\$/yr
<b>Total Costs</b>	<b>2,332,500</b>	<b>\$/yr</b>
<b>Profit</b>	<b>1,792,500</b>	<b>\$/yr</b>
Cost of Sales	606,250	\$/yr
Sales&Marketing Costs	1,726,250	\$/yr
<b>Profit after Tax</b>	<b>1,254,750</b>	<b>\$/yr</b>
<b>Total Profit after Tax (Whole USA)</b>	<b>10,038,000</b>	<b>\$/yr</b>

Figure 52 Financial Structure of Small Commercial Segment

To better monitor and understand the cost structure, it is imperative to calculate the Cost of Customer Acquisition (COCA) and the lifetime value of a customer (CLV). We arrive at these metrics based on an assumption of 90% retention over a period of 10 years, a sales commission rate of 20% considering a discount rate of 15% and a tax rate of 30% in our calculations. Our analysis reveals that given these assumptions, the CLV is significantly larger than COCA, which makes our proposition highly attractive to CSPs.

COCA & CLV Calculation		
<b>Retention rate</b>	90%	
<b>Contact length</b>	10	
<b>Discount rate</b>	15%	
<b>Tax rate</b>	30%	
<b>COCA</b>	\$17,262.50	Lifetime (10yr)
<b>Gross</b>		
<b>Contribution/customer</b>	\$12,547.50	Lifetime (10yr)
<b>Customer LifeTime Value (CLV)</b>	\$45,171.00	Lifetime (10yr)
<b>Contractor Commission</b>	\$5,500.00	\$/MW
<b>CLV - COCA</b>	\$27,908.50	Lifetime (10yr)

Figure 53 COCA and CLV calculation for Small Commercial Sales Structure

However, it is important to test our assumptions. We ran 2-way sensitivity tests for each of our assumptions and in the section below we highlight the most sensitive results.

### Sensitivity Analysis & Key Performance Indicators

Our tests reveal that our (CLV-COCA) index is most sensitive to two parameters – The retention rate and the Contractor Sales Commission. For example, if the retention rate falls to 60%, then even at a very low sales commission of 10%, the lifetime value of a customer falls below the customer acquisition costs deeming the business model unviable. More detailed results are computed below.

Sensitivity Test for (CLV - COCA) against Sales commission & Retention Rate					
Retention Rate	Contractor Sales Commission				
	\$27,908.50	10%	15%	20%	25%
	60.00%	-\$1,149.32	-\$2,361.82	-\$3,574.32	-\$4,786.82
	70.00%	\$5,128.06	\$3,691.94	\$2,255.83	\$819.72
	80.00%	\$14,992.50	\$13,205.00	\$11,417.50	\$9,630.00
	90.00%	\$32,748.50	\$30,328.50	\$27,908.50	\$25,488.50

Figure 54 Sensitivity Test Results

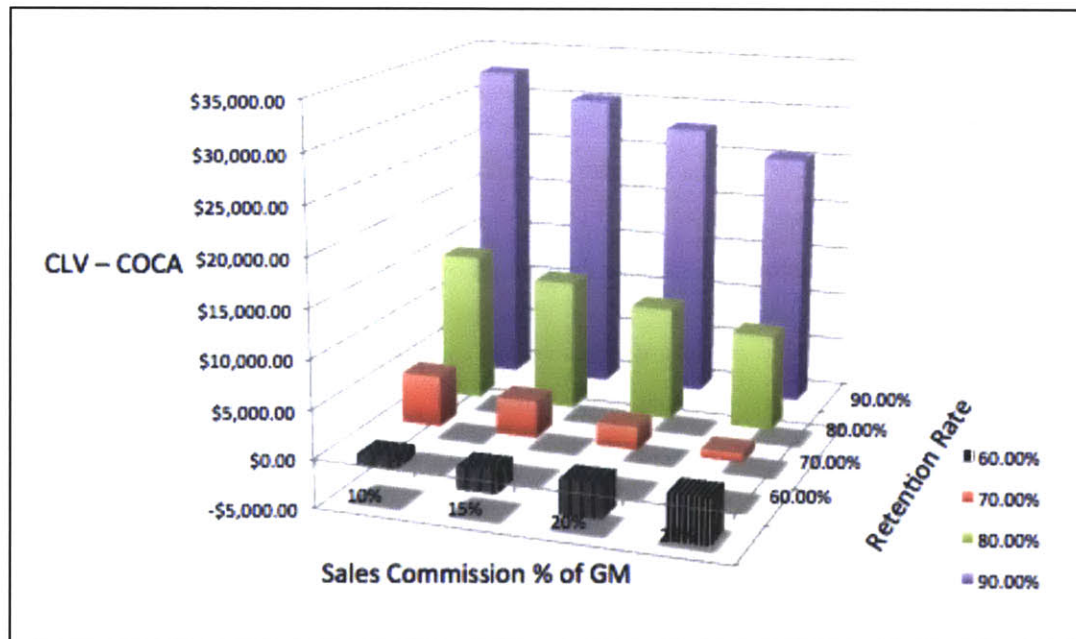


Figure 55 Graphic representation of effect of retention rates and sales commission on (CLV-COCA)

These results are a good indicator of the most important metrics that need to be monitored. As the profitability of this business model is sensitive to the customer retention rate, it is important that sales and marketing organization target only those customers that are likely to stick for a span of 10

years. Thus, schools, malls and shopping complex are better targets than coffee shops and bakeries. The management should continuously track the CLV and COCA values across each of these sub segments to distinguish the lucrative sectors from the unattractive ones. Another key measure would be \$/MW, which is a measure of the returns on assets and would help determine the efficiency of operations. The sales force need to be monitored and evaluated based on \$/MW as well, as it is a better indicator of profitability than just sales revenue. It is important that the incentive structure is aligned to profitability and retention than just revenue.

### **Recommendation on Sales and Marketing Strategy**

A firm should take on those functions that it can perform better and transact those functions that can be done by an intermediary. CSPs realize that they lack the capabilities to penetrate the small commercial sector and should actively look for channel partners with established business relations in this sector with local reach. They should construct composite channels consisting of some direct and some indirect elements.

We recommend a hybrid sales organization structure - direct sales force to cultivate relationship with large commercial and industrial customers, while an indirect sales forces incentivized to enroll small commercial customers. We further propose that the existing sales force be evaluated through behavior-based system, while the indirect sales force through outcome-based metrics.

After assessing different partnership models, we believe that Construction contractors could play the role of effective channel stewards that leverages their unmatched coverage from selling localized building improvement services while their sales force enables the energy management firms to penetrate the small commercial segment. With increased partnership, they could also play a role in demand generation and move up the value chain to become composite channel partners. The composite channel may present an ideal opportunity to the CSPs to blend power with trust and transparency to promote a higher level of channel performance(Rangan, 2006).

In the concluding chapter, we provide more strategic recommendations that could be adopted by CSPs to deal with disruptive innovation and to build long lasting competitive advantage.

## Chapter 8 – Environment Implications of Demand Response

Economic benefits of Demand Response programs have been the focus of numerous papers, but very few have delved into a quantitative assessment of environmental impact of DR. No energy technology treatise could be considered complete without a discourse into its environmental footprint.

It is a well-known fact that power plants emit greenhouse gases (GHG) and is the primary contributor to climate change. All avenues need to be explored to reduce our dependence on energy systems if we were to limit the damage to the ecosystem from rising GHG levels. Lately, the demand side management technologies are proving to be effective solutions in reducing the electricity demand and hence the emissions. According to the IEA's Alternative Policy Scenario demand side technologies could contribute to roughly 30% of the avoided CO<sub>2</sub> emissions in comparison to the Reference Scenario by 2030(Weisser, 2007).

Holland and Mansur (Holland & Mansur, 2006) show that real-time pricing of energy prices reduces variances in energy load because consumers curb energy use during higher-priced periods when demand is typically elevated. As less load variance corresponds with less reliance on peaking capacity, regions experience fewer emissions from real-time pricing when the base-power capacity is cleaner than peaking capacity<sup>10</sup>. Holland and Mansur find that in ERCT<sup>11</sup> region, emissions increase with demand reduction, as base-load emissions are more polluting than the marginal generators.

Rudkevich uses the concepts of marginal carbon intensity of electricity demand and shadow carbon intensity of transmission constraints to demonstrate that the Marginal Carbon Intensity of the grid is time and location dependent (Rudkevich, 2009). This chapter builds on the concept of marginal carbon intensity to investigate the environmental impact of load curtailment and displacement from demand response. It later compares the results against the environmental impact from pumped hydroelectric energy storage.

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<sup>10</sup> Holland and Mansur (2006)

<sup>11</sup> ERCT is a NERC sub-region located in Texas

Ruiz and Rudkevich define the marginal nodal carbon intensity of a specified node as “the decrease in CO2 emissions in the electrical network in response to an infinitesimal decrease in electricity demand at the specified node” (Ruiz & Rudkevich, 2010). Mathematically it is represented by

$$MCI_k(t) = \frac{\partial C(t)}{\partial L_k(t)}$$

Where  $L_k(t)$  is the demand at location  $k$  at time  $t$  and  $C(t)$  is the corresponding carbon emissions (Rudkevich, 2009). This formulation suggests that MCI can be negative or positive. Functionally, it signifies that if MCI is positive at a given location and time, an increase/decrease in demand leads to increase/decrease in CO2 emissions in the node. Likewise, a negative MCI signifies that demand and CO2 emissions in the node move in opposite directions at that given instant. A negative MCI can be exemplified by a scenario in which a demand reduction in the system causes the more polluting generators to increase their proportion of generation either due to system constraints or balancing needs resulting in increased CO2 emissions.

In a large regional grid, there could be multiple marginal generators in the system because of transmission constraints. Rudkevich characterizes the MCI for such a node by

$$MCI_k = \sum_{j=1}^m \alpha_{kj} \sigma_j$$

Where,

$MCI_k$  is the Marginal Carbon Intensity at location  $k$ ,

$\alpha_{kj}$  are the location-specific proportionality coefficients, and

$\sigma_1, \dots, \sigma_m$  are the CO2 emission rates of marginal units (Rudkevich, 2009).

We posit as demand response and pumped hydro curtails loads or displaces only marginal generators, the concept of marginal carbon intensity is well suited to investigate the environmental impact of load curtailment and displacement from demand response and pumped hydro technologies. In the following sections, we arrive at a methodology for calculating location specific proportionality coefficients. We then characterize the carbon savings resulting from demand



response and pumped hydro storage.

### **Formulation of Carbon Savings from Demand Response**

We derive the location-specific proportionality coefficient by appropriation of carbon intensities based on load contribution of each marginal generator at location  $k$ . We call this the load-weighted average, mathematically representing it as

$$\alpha_{kj} = \frac{\sum_{j=1}^m L_{kj} CF_{kj}}{L_k}$$

Where,  $L_{kj}$  is the Capacity of plant  $j$  at location  $k$

$CF_{kj}$  is the Capacity factor of plant  $j$  at location  $k$

$L_k$  is the Total Capacity available from the displaced marginal plants at location  $k$  at time  $t$

$$L_k = \sum_{j=1}^m L_{kj} CF_{kj}$$

During a DR event, the load is curtailed. Taking away the load and the corresponding marginal supply removes the entire carbon contribution from the displaced marginal generators. Thus, we characterize the Total savings in Carbon emissions during a DR event at time  $t$  in location  $k$  as

$$CS_k(t) = (1 - \delta) DMCI_k EC_k(t)$$

Where,  $DMCI_k$  is the displaced marginal carbon intensity at location  $k$

$EC_k(t)$  is the energy curtailed in location  $k$  at time  $t$

$\delta$  is the proportion of the load that is shifted instead of curtailed.

We define displaced marginal carbon intensity as the MCI before the curtailment event. One assumption that we make is that MCI of the grid remains the same between the duration of DR event and when the loads are back. A more detailed discussion on this will follow. The value of  $\delta$  depends on the type of load used.

If the DR event results in total curtailment of loads instead of just shifting of load, then,  $\delta = 0$ . In such a scenario, the Total Carbon Savings from DR event is

$$CS_k(t) = DMCI_k EC_k(t)$$

$$EC_k(t) = LC_k(t)d$$

Where,  $LC_k(t)$  is the average load curtailed in location k at time t

d is the duration of load curtailment in location k at time t

### **Formulation of Carbon Savings from Pumped Hydro**

Pumped hydro systems uses energy from base load power plants during off-peak hours to generate electricity in the peak hours. IEA describes these systems as “In periods of discharging (usually during daytime), the system generates power just like a conventional hydropower plant. In periods of charging (usually during night), water is pumped from a lower reservoir to an upper reservoir”(Inage, 2009).

In eGRID database, the carbon emission rates of pumped hydro plants  $\sigma_{p1}, \dots \sigma_{pm}$  are listed as zero lb/MWh. Pumped Hydro is treated in the same way as a base load hydroelectric plant. However, we propose cost allocation accounting principles be applied for carbon intensity calculations. Applying financial accounting principles to carbon intensity calculation, we propose that the carbon intensity of the energy used for pumping water upstream to reservoir be accounted towards calculation of carbon intensity of pumped hydro.

Let  $\sigma_{p1}, \dots \sigma_{pm}$  be the CO<sub>2</sub> emission rates of pumped hydro units 1 to m.

If  $\eta_p$  were the efficiency of pumped hydro systems then, the carbon intensity of a pumped hydro system can be characterized by

$\sigma_{p1}, \dots \sigma_{pm} = \sigma_b/\eta_p$ , where  $\sigma_b$  is the Base load Carbon Intensity. We choose the base load carbon intensity because typically the pumped hydro system is charged during off-peak hours when almost all the energy is supplied from the base load plants.

Total savings in Carbon emissions from dispatching pumped hydro plants at time t in location k

$$CS_{pk}(t) = (DMCI_k - \sigma_p) EC_k(t) = (DMCI_k - \sigma_b/\eta_p) EC_{pk}(t)$$

$$CS_{pk}(t) = (DMCI_k - \sigma_b/\eta_p) EC_k(t)$$

$EC_k(t)$  is the energy displaced in location k at time t by dispatching a pump hydro plant

$$EC_k(t) = LC_k(t)d$$

Where,  $LC_k(t)$  is the average load curtailed or displaced in location  $k$  at time  $t$

$d$  is the duration of load curtailment in location  $k$  at time  $t$

Formulation for the carbon savings from Demand Response and Pumped Hydro are summarized in the table 2 below.

Table 2 Carbon Savings from load curtailment and generator displacement

	Demand Response	Pumped Hydro
Carbon savings	$CS_k(t)$ $= (1 - \delta)DMCI_k EC_k(t)$	$CS_{pk}(t) = (DMCI_k - \sigma_b/\eta_p) EC_k(t)$

## Comparison of Environment Implications of DR against Pumped Hydro

CO<sub>2</sub> emissions are the primary environmental performance indicator of energy technologies due to their link to climate change. This study calculates environmental performance of energy in terms of CO<sub>2</sub>-equivalent units (CO<sub>2</sub>e). CO<sub>2</sub>e is a composite variable that includes the effects of CO<sub>2</sub>, N<sub>2</sub>O, and SO<sub>2</sub> emissions in terms of total global warming potential, and allows a more comprehensive analysis of the greenhouse gas effect from power generation.<sup>12</sup>

CO<sub>2</sub>e intensities for average marginal generating plants, *Marginal Carbon Intensity (MCI)*, and average total plants, *Average Carbon Intensity (ACI)*, are found for each region using eGRID 2010 data. The data include observed emissions intensities for eGRID regions for the 2007-operating year.

A simple comparison of marginal carbon intensity calculation based on system averages (NERC region – RFC avg.; Operator region –PJM avg.) and locational MCI for the same levels of load curtailment reveals a wide variance (see figure 56). This can be explained due to the inclusion of base load emissions in the system average computation. Considering only the marginal generators for the

<sup>12</sup> The Greenhouse Gas institute provides recommended figures for global warming potential (GWP), which consider the GHG effect of each gas as normalized against CO<sub>2</sub>. They are: GWPCO<sub>2</sub> = 1, GWpch<sub>4</sub> = 21, GWPN<sub>2</sub>O = 310

carbon intensity calculation is a more accurate representation of emission reductions in the region arising from load curtailment.

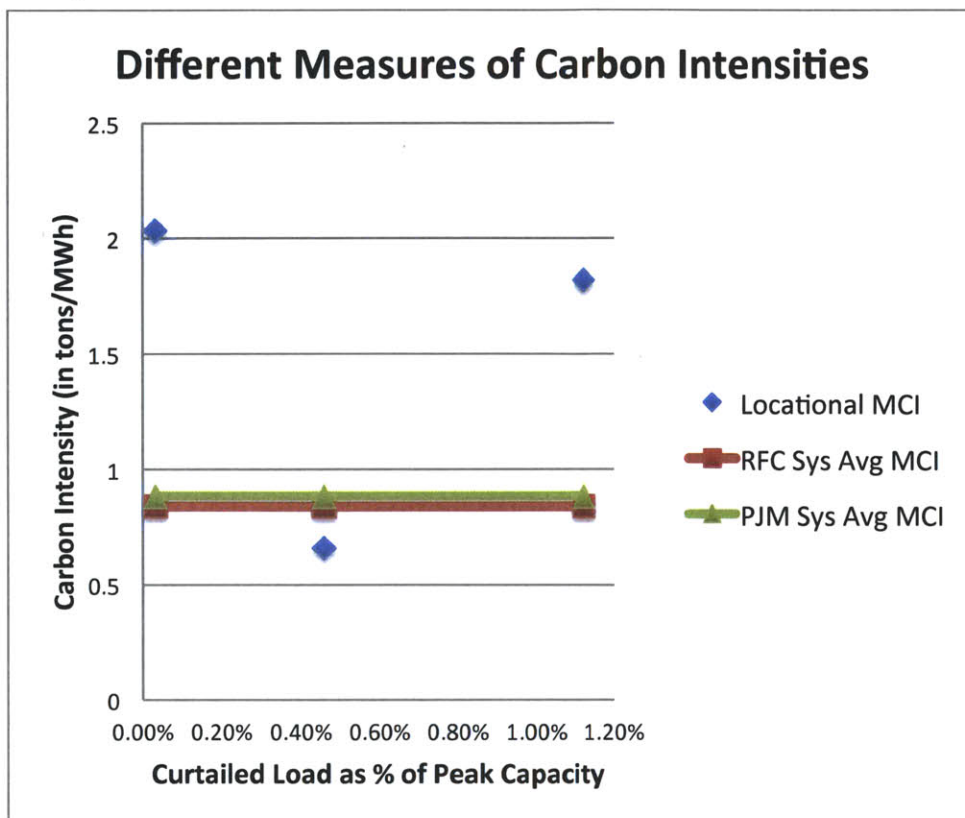


Figure 56. System Carbon Intensity and Locational Carbon Intensity across PJM DR Events- A Comparison

We investigated the carbon savings during DR events for two regional grids – ISO-NE and PJM. The results for PJM across three DR events were widely different from the savings computed using system average indicating that the carbon savings from load reductions cannot be aggregated and computed at the system level, as is the case with economic savings computation. Furthermore, the locational savings are different too across different DR events, demonstrating the context dependent characteristics of DR. The results are plotted in the figure 57 highlighting the sub-regions where the load was curtailed. To understand the difference in carbon savings it is important to understand the marginal generation mix at the locational level. A key finding is that the locations that produce the largest carbon savings from load curtailment are not much different in terms of resource mix from the rest of the region. The more polluting regions merely seem to have older and more polluting power plants.

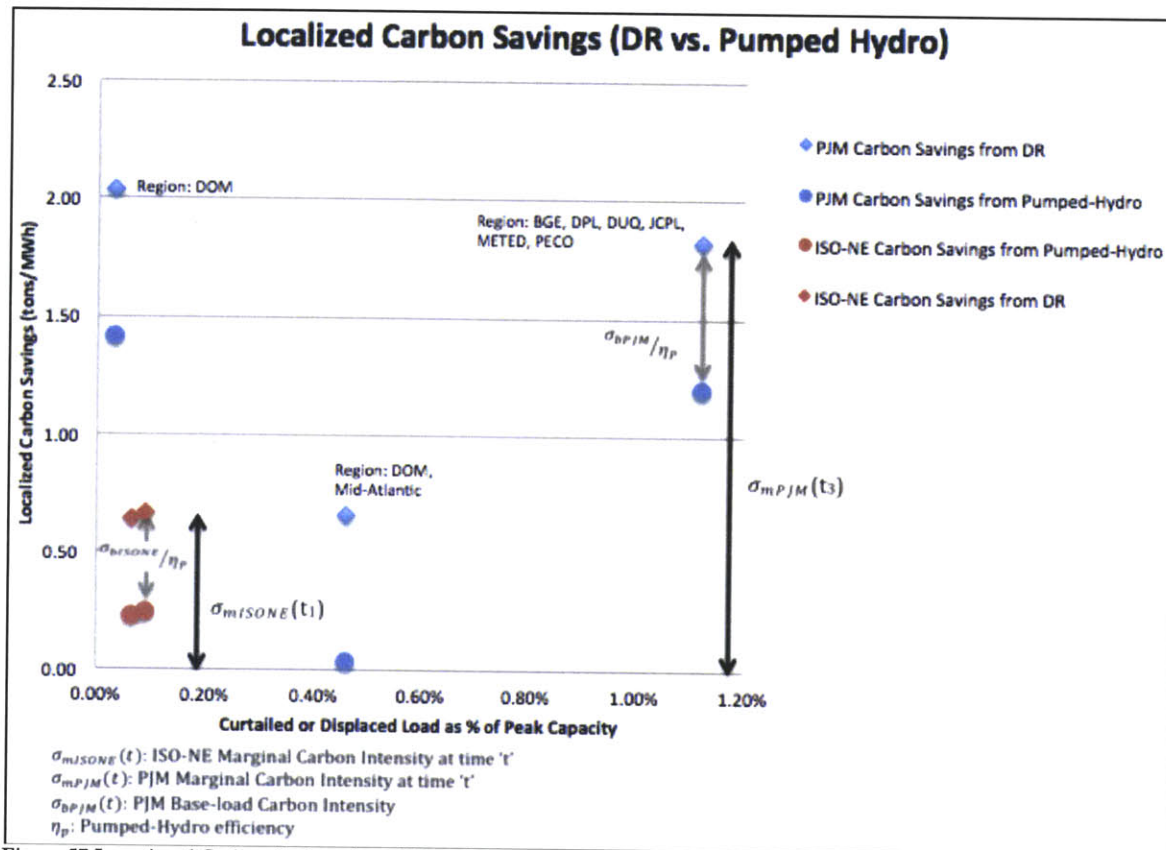


Figure 57 Local Carbon Savings from DR and Pumped Hydro

## Conclusion

The analyses demonstrate that the carbon savings when calculated using system wide carbon intensities differ substantially from those calculated with locational carbon intensities. Using these system wide carbon intensities to devise carbon abatement policies and structure the electricity market design rules could lead to inadequate and inconsistent results. Locational carbon intensity captures the location and time-specific dynamics of electricity demand and is therefore a better metric for evaluating total carbon savings from load curtailment and marginal power displacement.

Similar reductions in demand at different locations and times do not result in similar carbon savings, posing an uncertainty to the environment benefits for load reduction schemes. This is attributed to the difference in marginal and base-load generation fuels and efficiencies across regions. Adding a

carbon price to the marginal cost equation could change the dispatch order of plants and thus align carbon abatement policies with load reduction schemes (Rudkevich, 2009).

Demand response as a mechanism for load curtailment has proven to have higher economic benefits when compared to pumped hydro, largely due to significantly lower capital costs. The same cannot be concluded regarding the environment impacts due to the context dependent (time of use and location) characteristics of the marginal generators that both technologies displace.

## **Chapter 9 – Conclusion, Recommendation And Further Exploration**

The restructuring shaping the Electricity industry across the world is a systems problem cutting across interdisciplinary fields of technology, economics, public policy, environment and sociology. Decision makers that shape tomorrow's policy and investors that invest in financial and technological developments in this industry should rely on multiple decision models to make informed decisions. This thesis serves to provide one such decision model among many that could be used to understand the key dynamics shaping the industry. By no means, is this model an indicator of the forecast or future of the industry. It merely serves to help gain a systems understanding to a very complex and dynamic industry.

In the below section we offer some broad recommendations and dynamics that may affect the industry and policy structure.

### **Recommendations**

In this over a century old electric power industry, till very recently (and in many markets even now) electric companies were vertically integrated. The forces of deregulation has created a chain of sub-industries across the vertical and primarily so in services – Demand Response, Energy Efficiency, Energy Consulting, Energy Management, Energy Analytics, Distributed Generators, Energy Trading and Risk Management to name a few. Now, the industry can be assuredly classified as having a horizontal structure in the deregulated markets. Charles Fine in his famous book “Clockspeed” states, “Horizontal structures tend to create fierce, commodity-like competition within individual niches”. Such competition keeps players highly focused on their survival; only the best remain. Once a firm is large enough to exert some market power in its row, it sees the opportunity to expand vertically as well(Fine, 1998). We could see a similar pattern emerging in the Demand Response market space with Energy Services Companies (ESCOs) seeking out demand response firms or CSPs expanding into Energy Efficiency space.

### **Competition from Adjacent Markets (Expansion Opportunities)**

Demand Response should not be seen as a stand-alone business, instead firms operating in this space should consider operating a portfolio of such services including Energy Efficiency, ESCO, etc. Firms providing only one kind of service may not be able to sustain their business in the long run. Increasingly, the distinction between Energy Efficiency and Demand Response is getting blurred as firms providing one kind of service also diversify into the other realm. By providing a portfolio of energy management services, firms can provide turnkey, end-to-end solutions to consumers at significantly lower operational costs and thus garner more market share.

### **Building for Future Competencies**

Another dynamic that could shape the industry is the technical advancement in a niche and upcoming field such as analytics. This coupled with market power in another subsystem by the same firm could lead to product integration to develop proprietary integral product architectures creating a lock-in effect. Thus, CSPs should actively look to build competencies in analytics to give it a dominant vertical advantage. Market dynamics temper the relationship between the company's core capabilities and its performance (Utterback, 1993). Understanding the forces that move the market will lead the company to do a better job than rivals at sensing change and opportunities and then executing by evolving distinctive competencies.

### **Capabilities to Adapt to Cycles of Integration and Disintegration**

Charles Fine summarizes his double helix framework as "When the industry is vertical and the product architecture is integral, the forces of disintegration push toward a horizontal and modular configuration. On the other hand, when an industry has a horizontal structure, another set of forces push toward more vertical integration and integral product architectures" (Fine, 1998). The electricity demand-side industry is clearly horizontally structured post-deregulation, but it could go through these phases cyclically as well. In such cyclically changing environment, individual capabilities that are crucial in one era may become commodities in the next (Fine, 1998). As a result, more important than any individual capability is the ability to foresee the coming changes and continuously build those capabilities that will be of greatest value.



### **Disruption from Innovation**

There are other disruptive business models that are slowly emerging as the demand response market matures. One such model is consumers' offering their DR capacities on the reverse auction market to solicit bids from the CSPs. The consumers, then, select the CSP offering the highest price for its load. This has the direct consequence of increasing the transparency in the DR market and the consumers discovering the fair market value for their curtailable load. In return, the market operator collects a small percentage for each successful bid. Just like PayPal disrupted the banking industry by catering to smaller merchants and consumers through online platform, firms providing online platform to bring consumers and utilities/traders together to trade the curtailable loads at a fraction of the cost could disrupt the traditional CSPs.

However, for CSPs, worse still would be the scenario in which the utilities start bidding in the auctions and undercutting the CSPs with its scale advantage. Consequently, it drives down the margins of CSPs, while maximizing the benefits for the consumer. In some cases, it may even drive the CSPs out of business completely. In the face of such disruptive innovations, CSPs would not be able to sustain their margins just by aggregating DR capacity; they would need to reinvent themselves to become energy management firms providing integrated, automated turnkey energy services including energy efficiency services, risk management, planning, sourcing along with providing DR services. The CSPs would further need to invest in providing automated features to reduce their operational expenditure and lessen the consumer overhead.

### **Commoditization**

Commoditization is an unavoidable force in product lifecycles. Markets become increasingly commoditized as they mature. With increased adoption of DR, the DR market could follow a lifecycle path similar to other products and services in the past. The dynamic hypothesis arising from our system dynamics model also points to proliferation of competitors, over-estimation of demand and diminishing margins for CSPs. Weil illustrates through examples of how the sources of sustainable advantage become less intangible, as markets commoditize. "Competing on intangibles requires quite different capabilities from competing on product or service price and performance"(H. B. Weil, 2010). CSPs must build competencies in intangibles such as IP,

reputation, trust and customer experience to “out-compete” its rivals to be sustainable in the long run.

### **Delivering Great Customer Experience through Automation**

From our system dynamics model, it is evident that the DR adoption is dependent on the price and performance factors more than any other single factor. The CSPs must integrate technology in a seamless manner to automate DR and provide “set and forget” features to reduce the overhead associated with DR and improve DR performance. Providing a seamless and effective service creates a great customer experience, leading to a sticky effect that makes the customer more unwilling to switch service provider.

### **Opt-Out (Presumed Consent) Policy for pricing and AMI deployment**

When framing policies for dynamic pricing or AMI deployment, implications of Opt-in versus an Opt-out program must be explored. It is a well known fact that a default opt-out policy, wherein consumers are signed on to the new scheme by default results in increased adoption, but nevertheless such programs must be rolled out after thorough analysis to prevent consumer distrust and dissatisfaction. It is also important to consider the impact of rolling out multiple programs and rate changes one after another. For instance, an AMI rollout followed by a rate increase to cover the costs of the AMI rollout could lead to drastic distrust in the system towards future policies.

### **Accounting Externalities into Costs**

Gillingham et.al (2009) in their paper assert that energy prices do not reflect the true marginal social cost of energy consumption, either because of environmental externalities, average-cost pricing, or national security(Gillingham, Newell, & Palmer, 2009). Having a policy that charges a cost for carbon or a cap and trade system will ensure that the energy consumer internalizes the costs arising from these externalities. These added costs could in turn lead to increase in DR adoption.

Gillingham et.al (2009) also suggest better education of consumer and product standards to overcome potential behavioral failures arising from bounded rationality and heuristic decision making that could hamper the adoption of demand-side technologies.

## **Dispatch Merit Order**

The dispatch merit order is the way of ranking generation resources for dispatch onto the grid. Usually the merit order is economic based on the marginal operating costs. A policy that encourages increased integration of renewable technologies by conferring renewable resources such as Solar and Wind precedence over other fossil based marginal plants would lead to increased adoption of DR. This has the effect of increasing the VER integration to the grid. Here, DR could serve as a grid balancing resource in regions with increased integration of VER into the grid.

Most mature markets do not see new competition due to high barriers to entry. However, innovative technologies from adjacent markets can disrupt mature markets and change its dynamics(H. Weil, 2004). We see this phenomenon repeating in the electric industry. In such markets, the incumbents do not initially explore the newly revealed opportunities due to lower income prospects from these technologies compared to those generated from their existing portfolio. The business opportunity could be enormous for a firm that understands the dynamics and evolves a business model that exploits them.

## **Further Exploration**

### **Model Development**

As electricity markets deregulate further, the forces that affect the industry become more dynamic and competitive bringing with it societal benefits and increased uncertainty. The traditional strategy assessment tools such as capability analysis, value chain analysis, etc. become ineffective to deal with uncertainty and competition(Courtney et al., 1997). A wide range of scenarios can be envisioned in the future and to deal with uncertainties. These scenarios can be explored along with system dynamics model. We have seen in the scenario section that the effect of increased energy prices (LMP) could fuel increased DR capacity and increased rate of DR adoption. Compound scenarios such as rapid inflation in energy prices and adoption of climate change policies (carbon tax or cap and trade systems) could be explored further to see the impact of alternate futures and plan contingencies to deal with them.

In our system dynamics model, it can be difficult to assign weights for the components that define the behavioral dynamics of the system. This is because these weights are based on subjective determination of the multi-criteria scoring model. This methodology can be further refined using Analytical Hierarchy Process, which is a more structured approach for determining the scores and weights for the multi-criteria scoring model. It is a powerful tool for decision making in situations where multiple objectives are present. AHP provides a framework to incorporate multi-criteria, multi-actor decisions that may be based on rational and/or intuitive preferences (Saaty, 1986).

One area to explore would be to use AHP to model the willingness to adopt DR. It is a three-step process. To model the willingness to adopt DR using an AHP, the objective, the criteria, and possible alternatives are first defined. The objective is the willingness to adopt DR. The criteria are opinions of the stakeholders. In our system, the stakeholders include consumers (from each class namely- industrial, commercial and residential), CSPs, utility, and the ISO. The alternatives are the electricity price, DR overhead, performance, social value, risk and complementary assets. Once the objective, the criteria, and possible alternatives are defined, opinions of all stakeholders should be considered using a survey methodology. Then, simple pairwise comparisons can be carried out to generate a judgment matrix. Finally, the overall priorities for ranking the alternatives are determined using Eigen vectors to assign the weights for the model.

### **Business Model Development**

Malone et al (Malone et al., 2006) define four basic business models based on what asset rights are sold and four variations on the type of assets involved. Using this framework, the value chain players can be delineated based on their business models in the electricity reserve market. It could be used as a framework to guide innovative business models.

### **Carbon Study of DR**

Locational carbon intensities methodology proposed in this thesis provides a simplified formulation intended to provide a directionally correct approach to calculate carbon savings. A more accurate representation would require actual data about time dependent carbon emissions of the marginal

plants, the inlet energy sources and outlet losses for pumped hydro. The data needed for accurate representation is beyond the scope of the current study and is a topic for further exploration.

Understanding the dynamics of the Marginal Carbon Intensity differential from load displacement offers further opportunity for research. It is estimated by several studies that displaced peak demand is not all curtailed (or conserved) energy, and some of this demand is likely displaced to off-peak hours. Understanding the characteristics of energy curtailment and displacement can improve upon using MCI differential as a metric for understanding how adding different load displacement strategies such as real-time pricing, DR, or pumped hydro, will perform in terms of carbon emissions.

Demand Response has the added benefit of economic and carbon emission savings arising from avoided costs of constructing and operating newer peaking plants (Federal Energy Regulatory Commission, 2009a). These savings are not currently accounted for in our computations and are a topic for future discourse that captures the total societal and lifecycle benefits from load curtailment and displacement.

## **Concluding Thoughts**

Most complex problems can be modeled using system dynamics. The structure and the dynamics help not only the modeler but also the decision maker gain a mastery of the problem and the system. The dynamics and the key parameters that have emerged from the System Dynamics model has lent insights into the crucial success factors within the framework of technology planning, strategic management and policy analysis. Only through gaining such insights can we make informed decisions that go towards solving the grand challenge of energy, poverty, and climate change.

## Glossary

**Ancillary services** Those services necessary to support the transmission of electric power from seller to purchaser given the obligations of control areas and transmitting utilities within those control areas to maintain reliable operations of the interconnected transmission system [FERC].

**Capacity charge** An element in a two-part pricing method used in capacity transactions. The capacity charge, also called Demand Charge, is assessed on the amount of capacity being purchased (EIA, n.d.).

**Capacity payment** Compensation for making available generation capacity.

**Curtailement Service Provider (CSP)** Curtailement Service Provider, also referred as Demand Response Aggregator, provides demand response services to retailer, utility or ISO.

**Congestion** A condition that occurs when insufficient transfer capacity is available to implement all of the preferred schedules for electricity transmission simultaneously (EIA, n.d.).

**Capacity payment** Compensation for making available generation capacity.

**Cost of Customer Acquisition (COCA)** Cost associated with acquiring a customer (includes all marketing and sales costs).

**Customer Lifetime Value (CLV)** Net present value of cash flows attributed to the relationship with a customer over its lifetime.

**Distributed Generation (DG)** Generation that is located close to the load or consumer that it is intended to serve.

**Energy Service Companies (ESCOs)** A firm providing energy services to consumers; services include demand response, energy efficiency, power reliability and quality services, billing support, etc.

**Federal Energy Regulatory Commission (FERC)** The Federal agency with jurisdiction over interstate electricity sales, wholesale electric rates, hydroelectric licensing, natural gas pricing, oil pipeline rates, and gas pipeline certification.

**Financial Transmission Right (FTR)** A right to receive financial compensation for the difference between actual congestion charges and the price of the FTR (Shively & Ferrare, 2010).

**Futures contract** A supply contract between electricity buyer and seller of a fixed amount of electricity at an agreed price and location at a future period in time.

**Independent System Operator (ISO)** An independent, federally regulated entity established to coordinate regional transmission in a non-discriminatory manner and ensure the safety and reliability of the electric system (FERC).

**Locational marginal pricing (LMP)** Cost to serve the next MW of load at a specific location, using the lowest production cost of all available generation, while observing all transmission limits.

**Marginal Carbon Intensity (MCI)** The decrease in CO<sub>2</sub> emissions in the electrical network in response to an infinitesimal decrease in electricity demand at the specified node (Ruiz & Rudkevich, 2010).

**Retailer** Electric power utilities selling electric supply to end consumers.

**Spot Market** The day-ahead or hour-ahead market for electricity for short-notice electricity trades.

**Variable Energy Resource (VER)** A generator for which output varies over time and is imperfectly predictable, e.g., wind and solar farms (MIT Interdisciplinary Study, 2011).

**Wholesale Trading** – The trading of electricity between market participants such as generators, utilities and marketers.

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## Appendix

The formulation of the system dynamics model is listed below.

- (001) Adoption due to Marketing=  
 $\text{Potential DR capacity} * \text{Marketing Effectiveness}$   
 Units: MW
  
- (002) "Aggr. DR capacity"= INTEG (  
 $\text{DR adoption rate},$   
 $100)$   
 Units: MW [0,?]
  
- (003) AMI Penetration=  
 $0.01$   
 Units: Dmnl
  
- (004) Capacity addition rate=  
 $\text{MAX}(\text{DELAY3}(\text{Change in Demand} * \text{Effect of Capa Utilization on Capa Additions}$   
 $* \text{Effect of LMP on Capa Additions}, 3), 0)$   
 Units: MW/Yr
  
- (005) Capacity Factor=  
 $\text{TB EXO CF}(\text{Time}) / (1 + ("Aggr. DR capacity") / \text{Power Plant Capacity})$   
 Units: Dmnl
  
- (006) Capacity Payment to Customer=  
 $"Aggr. DR capacity" * \text{Fraction of LMP to customer}$   
 Units: \$/Yr
  
- (007) Capital per yr=  
 $\text{Total Cost}$   
 Units: \$/Yr
  
- (008) Change in Capacity=  
 $\text{Capacity addition rate} - \text{Plant Decomission rate}$   
 Units: MW/Yr
  
- (009) Change in Demand=  
 $\text{TB EXO DMND}(\text{Time}) - \text{Demand Reduction from EE}$   
 Units: MW/Yr
  
- (010) Change in Demand Reduction=  
 $\text{TB EXO DMND REDUCT}(\text{Time}) * \text{Effect of LMP SDS Shortfall on EE}$   
 Units: MW/Yr
  
- (011) Change in EV Penetration=

- $$(1 + \text{Effect of DR on Complementary Assets adoption}) * \text{EV Change from external factors}$$

$$/ \text{Time to EV change}$$
Units: Prc/Yr
- (012) Change in LMP=
$$12 * \text{TB EXO PRC}(\text{Time}) * \text{Effect of shortfall on LMP} * \text{Volatility Factor}$$
Units: \$/(MW\*Year)
- (013) "Change in Pot. DR Capa"=
$$\text{TB EXO POTDRCAPA}(\text{Time})$$
Units: MW/Yr
- (014) Change in VER percent=
$$(1 + \text{Effect of DR on Complementary Assets adoption}) * \text{VER change from external factors}$$

$$/ \text{Time to VER change}$$
Units: Prc/Yr
- (015) Cumulative Costs= INTEG (
$$\text{Capital per yr,}$$

$$100000)$$
Units: \$
- (016) Cumulative Profits= INTEG (
$$\text{Profits,}$$

$$1)$$
Units: \$
- (017) Demand Reduction from EE= INTEG (
$$\text{Change in Demand Reduction,}$$

$$10000)$$
Units: MW
- (018) Desired Mkt Share=
$$0.1$$
Units: Dmnl
- (019) "DR % of Peak Demand"=
$$\text{"Aggr. DR capacity"}/\text{Peak Demand}$$
Units: Dmnl
- (020) DR adoption rate=
$$\text{MAX}(\text{Adoption due to Marketing} * \text{Willingness to adopt DR}/\text{Time to adopt DR}, 0)$$
Units: MW/Yr
- (021) DR Overhead=
$$\text{"Short term Supply-Demand Shortfall"} * \text{"DR \% of Peak Demand"} * 100$$

Units: Dmnl

- (022) effect of avg elec price on adoption=  
TB EFF ELECPRC ADPT(LMP)  
Units: Dmnl
- (023) Effect of Capa Utilization on Capa Additions=  
TB EFFCF CAPA(Capacity Factor)  
Units: Dmnl
- (024) effect of comp on exiting=  
Mkt Share Variance  
Units: Dmnl
- (025) Effect of Complementary Assets on adoption=  
TB EFF COMP ASST ADPT(EV Penetration+Percent of VER Capa)  
Units: Dmnl
- (026) effect of DR OH on adoption=  
TB EFF DROH ADPT(DR Overhead)  
Units: Dmnl
- (027) Effect of DR on Complementary Assets adoption=  
TB EFF DR COMPASST("DR % of Peak Demand")  
Units: Dmnl
- (028) Effect of Hedges on Price Risk=  
TB EFF HDG PRCRSK(ABS(LMP-Hedge Prices))  
Units: Dmnl
- (029) Effect of LMP on Capa Additions=  
TB EFFLMP CAPA(LMP)  
Units: Dmnl
- (030) Effect of LMP SDShortfall on EE=  
TB EFF LMP SHRTLL EE(LMP\*"Short term Supply-Demand Shortfall")  
Units: Dmnl
- (031) effect of Mkt Opp on entry rate=  
DELAY1(TB EFF MKTOPP ENTRY(Mkt Opportunity),1)  
Units: Dmnl
- (032) effect of number of DR players on product improvement=  
TB EFFDR PD IMP(Number of DR players)  
Units: Dmnl
- (033) Effect of Performance on adoption=  
TB EFF PERF ADPT(Performance Index)

- Units: Dmnl
- (034) effect of returns on exiting=  

$$\text{TB EFF PFT EXIT}(\text{Cumulative Profits/Cumulative Costs})$$
Units: Dmnl
- (035) Effect of Returns on PD and Marketing=  

$$\text{TB EFPRFT PD MKTG}(\text{Cumulative Profits/Cumulative Costs})$$
Units: Dmnl
- (036) Effect of Risk Index on adoption=  

$$\text{TB EFF RSK ADPT}(\text{Perceived Risk Index}) + \text{Volatility Factor}$$
Units: Dmnl
- (037) effect of share variance on PD and Mktg=  

$$\text{TB EFFMKTSHR PD MKTG}(\text{Mkt Share Variance})$$
Units: Dmnl
- (038) Effect of shortfall on LMP=  

$$\text{TB EFFSF LMP}(\text{"Short term Supply-Demand Shortfall"})$$
Units: Dmnl
- (039) Effect of VER EV on Volume Risk=  

$$\text{TB EFF VEREV VOLRSK}(\text{EV Penetration} + \text{Percent of VER Capa})$$
Units: Dmnl
- (040) Entry rate=  
effect of Mkt Opp on entry rate  
Units: 1/Yr
- (041) EV Change from external factors=  
0.1  
Units: Prc
- (042) EV Penetration= INTEG (   
Change in EV Penetration,  
0.1)  
Units: Prc
- (043) Exit Rate=  
IF THEN ELSE( Number of DR players < "minimum no. of companies" , 0 ,  
Norm Exit Rate  
\*(1 + (effect of comp on exiting + effect of returns on exiting)))  
Units: 1/Yr
- (044) Expected Grid Reliability=  
1  
Units: Dmnl

- (045) FINAL TIME = 20  
Units: Year  
The final time for the simulation.
- (046) Fixed Operating Cost per MW Capa=  
1500  
Units: \$/MW
- (047) Fraction of LMP to customer=  
$$\text{LMP} * (\text{TB EFF DRFIRMS FRACT}(\text{Number of DR players}))$$
  
Units: \$/MW
- (048) Hedge Prices=  
$$\text{DELAY1I}(\text{LMP}, 1, 36000)$$
  
Units: \$/MW
- (049) INITIAL TIME = 0  
Units: Year  
The initial time for the simulation.
- (050) "Level of Process & Technology"= INTEG (  
Product Improvement Rate,  
0.1)  
Units: Dmnl
- (051) LMP= INTEG (  
Change in LMP,  
36000)  
Units: \$/MW
- (052) Market Share=  
$$1 / \text{Number of DR players}$$
  
Units: Dmnl
- (053) Marketing Effectiveness=  
$$\text{TB EFF MKTG BUDGT EFFECT}(\text{Mktg Sales Outlay})$$
  
Units: Dmnl
- (054) "minimum no. of companies"=  
4  
Units: Dmnl
- (055) Mkt Opportunity=  
$$\text{DR adoption rate} * (\text{Total Expected DR Cap} - \text{"Aggr. DR capacity"}) / \text{"Aggr. DR capacity"}$$
  
Units: MW/Yr



- (056) Mkt Share Variance=  
 $\text{MAX}(0, (\text{Desired Mkt Share} - \text{Market Share}) / \text{Desired Mkt Share})$   
 Units: Dmnl
- (057) Mktg Sales Outlay=  
 $\text{Revenue} * \text{Effect of Returns on PD and Marketing} * \text{effect of share variance on PD}$   
 and Mktg  
 $* \text{Norm Frac Mktg}$   
 Units: \$/Yr
- (058) Norm Exit Rate=  
 $\frac{2}{\text{Yr}}$   
 Units: 1/Yr
- (059) Norm Frac Mktg=  
 $\frac{0.35}{\text{Dmnl}}$   
 Units: Dmnl
- (060) Norm Frac PD=  
 $\frac{0.05}{\text{Dmnl}}$   
 Units: Dmnl
- (061) Norm PD Budget=  
 $\frac{1e+06}{\text{Yr}}$   
 Units: \$/Yr
- (062) Norm PD Productivity=  
 $\frac{0.2}{\text{Yr}}$   
 Units: 1/\$
- (063) Number of DR players= INTEG (  
 $\text{Entry rate} - \text{Exit Rate},$   
 $\frac{2}{\text{Yr}})$   
 Units: Dmnl [0,?]
- (064) Other Variable Costs=  
 $\text{Mktg Sales Outlay} + \text{Product Dev Budget}$   
 Units: \$/Yr
- (065) PD Productivity=  
 $(\text{Norm PD Productivity} / \text{"Level of Process \& Technology"}) * \text{effect of number of DR}$   
 players on product improvement  
 Units: 1/\$
- (066) Peak Demand=  
 $\text{TB EXO PKDMND}(\text{Time})$   
 Units: Dmnl

- (067) Perceived Risk Index=  
 $\text{DELAY1I}(1/(\text{"Level of Process \& Technology"}, 2, 1))$   
 Units: Dmnl
- (068) Percent of VER Capa= INTEG (  
 Change in VER percent,  
 1.5)  
 Units: Prc
- (069) Performance Index=  
 "Level of Process \& Technology"  
 Units: Dmnl
- (070) Plant Decomission rate=  
 1000  
 Units: MW/Yr
- (071) Potential DR capacity= INTEG (  
 "Change in Pot. DR Capa"-DR adoption rate,  
 4000)  
 Units: MW [0,?]
- (072) Power Plant Capacity= INTEG (  
 Change in Capacity,  
 850000)  
 Units: MW
- (073) Product Dev Budget=  
 Norm Frac PD\*Revenue\*Effect of Returns on PD and Marketing\*effect of share  
 variance on PD and Mktg  
 Units: \$/Yr
- (074) Product Improvement Rate=  
 $\text{MAX}(\text{DELAY1}(\text{PD Productivity*Product Dev Budget*TB EFF AMI PD(AMI}$   
 Penetration  
 $\text{)/Norm PD Budget , Time to Product improvement}),0)$   
 Units: 1/Yr
- (075) Profits=  
 Revenue-Total Cost  
 Units: \$/Yr
- (076) Regulatory Risk=  
 0.7  
 Units: Dmnl
- (077) Reserve Margin=  
 $(\text{Power Plant Capacity}/\text{Total Demand})-1$

Units: Dmnl

(078) Revenue=  
"Aggr. DR capacity"\*LMP  
Units: \$/Yr

(079) SAVEPER =  
TIME STEP  
Units: Year [0,?]  
The frequency with which output is stored.

(080) "Short term Supply-Demand Shortfall"=  
MAX( 0 , 1-Capacity Factor\*(1+Reserve Margin) )  
Units: Dmnl

(081) Social Value=  
Expected Grid Reliability\*"DR % of Peak Demand"  
Units: Dmnl

(082) TB EFF AMI PD(  
[(0,0)-(1,1)],(0,0.5),(0.05,0.6),(0.1,0.7),(0.2,0.8),(0.3,0.9),(0.401222,  
0.957143),(0.5,0.98),(0.6,0.99),(0.7,0.99),(0.8,1),(1,1))  
Units: \*\*undefined\*\*

(083) TB EFF COMP ASST ADPT(  
[(0,0)-(100,1)],(0,0),(100,1))  
Units: \*\*undefined\*\*

(084) TB EFF DR COMPASST(  
[(0,0)-(1,1)],(0,0),(1,1))  
Units: \*\*undefined\*\*

(085) TB EFF DRFIRMS FRACT(  
[(0,0)-(100,1)],(0,0),(1,0.2),(2,0.25),(3,0.26),(4,0.3),(5,0.31),(6,0.33),  
(7,0.35),(8,0.38),(10,0.4),(100,0.4))  
Units: \*\*undefined\*\*

(086) TB EFF DROH ADPT(  
[(0,0)-(1,1)],(0,0),(0.0468432,0.195238),(0.120163,0.461905),(0.193483,0.652381),  
(0.285132,0.785714),(0.403259,0.890476),(0.541752,0.966667),(0.678208,0.980952),  
(1,1))  
Units: \*\*undefined\*\*

(087) TB EFF ELECPRC ADPT(  
[(0,0)-(120000,6)],(10000,0.1),(22973.5,0.4),(36904.3,0.771429),(49124.2,  
1.45714),(58900.2,2.14286),(66232.2,2.6),(77963.3,3.31429),(87983.7,4),(97026.5,  
4.74286),(108024,4.88571),(119756,5))  
Units: \*\*undefined\*\*

- (088) TB EFF HDG PRCRSK(  
 [(0,0)-(50000,1)],(0,0),(5000,0.25),(10000,0.5),(20061.1,0.633333),(28513.2  
 ,0.704762),(38696.5,0.814286),(50000,1))  
 Units: Dmnl
- (089) TB EFF LMP SHRTLLE EE(  
 [(0,0)-(30000,2)],(0,0),(2000,0.5),(4000,0.75),(6000,1),(8000,1.1),(10000  
 ,1.15),(15000,1.2),(20000,1.25),(30000,1.3))  
 Units: Dmnl
- (090) TB EFF MKTG BUDGT EFFCT(  
 [(0,0)-(1e+09,1)],(0,0),(100000,0.001),(1e+06,0.01),(5e+06,0.1),(1e+07,0.12  
 ),(1e+08,0.2),(5e+08,0.25),(1e+09,0.3))  
 Units: Dmnl
- (091) TB EFF MKTOPP ENTRY(  
 [(0,0)-(100000,100)],(0,0),(100000,20))  
 Units: Dmnl
- (092) TB EFF PERF ADPT(  
 [(0,0)-(1,1)],(0,0.6),(0.5,0.75),(1,1))  
 Units: Dmnl
- (093) TB EFF PFT EXIT(  
 [(-1,0)-(1,10)],(-1,10),(-0.5,2),(0,1),(0.1,0),(1,0),(1,0))  
 Units: \*\*undefined\*\*
- (094) TB EFF RSK ADPT(  
 [(0,0)-(1,1)],(0,0),(1,1))  
 Units: Dmnl
- (095) TB EFF VEREV VOLRSK(  
 [(0,0)-(100,1)],(0,0),(2,0.05),(5,0.1),(10,0.2),(15,0.3),(20,0.4),(25,0.5  
 ),(50,0.9),(100,1))  
 Units: \*\*undefined\*\*
- (096) TB EFFCF CAPA(  
 [(0,0)-(1,2)],(0,0),(0.250509,0.285714),(0.5,0.5),(0.75,1),(0.796334,1.0381  
 ),(0.818737,1.06667),(0.85336,1.13333),(0.88,1.2),(0.904277,1.26667),(0.95112  
 ,1.37143),(1,1.5))  
 Units: \*\*undefined\*\*
- (097) TB EFFDR PD IMP(  
 [(1,0)-(50,3)],(1,1),(2.69654,1.27143),(4.49287,1.5),(7.18737,1.78571),(10.4807  
 ,2.1),(13.2749,2.32857),(18.0652,2.54286),(22.6558,2.67143),(26.5479,2.74286  
 ),(32.2363,2.82857),(37.9246,2.88571),(43.9124,2.92857),(50,3))  
 Units: \*\*undefined\*\*

- (098) TB EFFLMP CAPA(  
 [(30000,0)-(250000,2)],(30000,0.8),(41201.6,0.866667),(51955.2,0.942857),  
 (64949.1,1.10476),(76150.7,1.30476),(86904.3,1.57143),(101242,1.98095),(105275  
 ,2.01905),(153300,2),(205200,2),(249491,2))  
 Units: \*\*undefined\*\*
- (099) TB EFFMKTSHR PD MKTG(  
 [(0,0)-(1,1.5)],(0,1),(0.14664,1.04286),(0.303462,1.12857),(0.474542,1.19286  
 ),(0.578411,1.27143),(0.694501,1.35),(0.892057,1.46429),(1,1.5))  
 Units: Dmnl
- (100) TB EFFSF LMP(  
 [(0,0)-(1,2)],(0,1),(0.05,1.02),(0.1,1.05),(0.15,1.10476),(0.2,1.15238),(  
 0.25,1.2),(0.3,1.31429),(0.419552,2),(1,2))  
 Units: \*\*undefined\*\*
- (101) TB EFPRFT PD MKTG(  
 [(-1,0)-(1.5,1.25)],(-0.994908,0.571429),(-0.786151,0.64881),(-0.557027,0.72619  
 ),(-0.241344,0.821429),(0.0132383,0.904762),(0.14053,1),(0.476578,1.01786)  
 ,(0.761711,1.03571),(1.10794,1.05357),(1.29124,1.07738),(1.5,1.08929))  
 Units: Dmnl
- (102) TB EXO CF(  
 [(0,0)-(20,1)],(0,0.8),(20,0.82))  
 Units: Dmnl
- (103) TB EXO DMND(  
 [(0,0)-(20,100000)],(0,10000),(2,22860),(4,28290),(6,33710),(8,26670),(10  
 ,19570),(12,30050),(14,24000),(16,23950),(18,22860),(20,24760))  
 Units: \*\*undefined\*\*
- (104) TB EXO DMND REDUCT(  
 [(0,0)-(20,4000)],(0,0),(2,327),(3,852),(4,1687),(6,3748),(10,1101),(12,1200  
 ),(14,1600),(16,2500),(18,2000),(20,1000))  
 Units: MW
- (105) TB EXO PKDMND(  
 [(0,0)-(20,4e+06)],(0,3.64e+06),(20,4e+06))  
 Units: Dmnl
- (106) TB EXO POTDRCAPA(  
 [(0,0)-(20,20000)],(0,500),(2,1000),(4,2000),(6,3400),(8,4800),(10,4100),  
 (12,1200),(14,0),(16,0),(18,0),(20,0))  
 Units: Dmnl
- (107) TB EXO PRC(  
 [(0,0)-(20,10000)],(0,0),(1,300),(20,300))

- Units:  $\$/(\text{MW} \cdot \text{Month})$
- (108) TIME STEP = 1  
Units: Year [0,?]   
The time step for the simulation.
- (109) Time to adopt DR=  
1  
Units: Yr
- (110) Time to EV change=  
1  
Units: 1/Yr
- (111) Time to Product improvement=  
2  
Units: Yr
- (112) Time to VER change=  
1  
Units: 1/Yr
- (113) Total Cost=  
"Aggr. DR capacity"\*Fixed Operating Cost per MW Capa+Capacity Payment to  
Customer  
+Other Variable Costs  
Units:  $\$/\text{Yr}$
- (114) Total Demand= INTEG (  
Change in Demand,  
700000)  
Units: MW
- (115) Total Expected DR Cap=  
38000  
Units: MW
- (116) VER change from external factors=  
0.3  
Units: Prc
- (117) Volatility Factor=  
Effect of VER EV on Volume Risk+Regulatory Risk+Effect of Hedges on Price  
Risk  
Units: Dmnl
- (118) "Willingness to adopt based on Performance-Price"=  
MAX(0,effect of avg elec price on adoption+Effect of Performance on adoption

-effect of DR OH on adoption)  
Units: Dmnl

(119) Willingness to adopt DR=  
MAX(Effect of Complementary Assets on adoption+Social Value+"Willingness to  
adopt based on Performance-Price"  
-Effect of Risk Index on adoption, 0)  
Units: Dmnl